Preliminary results of the Marine Scientific Research program: PhilEx Exploratory Cruise Research Vessel Melville 6 June to 3 July 2007, Manila to Manila

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Prepared 1 August 2007

I Introduction:

This report filed by the cruise Chief Scientist Arnold L. Gordon, presents the preliminary results of the Marine Scientific Research program entitled PhilEx Exploratory Cruise, which took place from the US research vessel Melville from 6 June to 3 July 2007, Manila to Manila. However, before presenting the preliminary results a brief overview of the PhilEx program is presented, including the relationship of the Exploratory Cruise to the other field cruises of PhilEx.

II PhilEx Objectives:

The complex land/water configuration characteristic of an archipelago leads to an oceanic dynamic regime that is not fully understood and only poorly simulated in numerical models. Philippines Straits Dynamics Experiment [PhilEx], organized and implemented by a group of university and research institution scientists, is a basic research oceanographic project that has been formulated to improve our understanding and ability to model the circulation within the Philippine archipelagos. The complexity of the oceanography within the Philippine archipelago present daunting challenges not just to the observational program, but also to proper numerical simulation. These challenges arise from the difficulty in distinguishing between the competing processes that shape the ocean circulation, all of which have spatial and temporal characteristics.

The PhilEx goal is to enhance our understanding of the oceanographic processes and features arising in and around straits, and improve our capability to predict the inherent spatial and temporal variability of these regions using models and advanced data assimilation techniques. Features and processes of interest are those which drive the local spatial variability on short time scales, via their relation to abrupt topography and their interaction with the mean flow, tidal and seasonal cycles.

The resultant numerical model, honed by observations, and the enhanced understanding of the oceanography of the Philippine waters to be produced by the PhilEx program will have a multitude of applications in managing marine resources and the marine environment of the Philippines, as well as for issues of marine safety and prediction of marine pollution dispersion.

PhilEx involves many researchers from the USA and from The Philippines. The US PhilEx Chief Scientist is Arnold L. Gordon of the Lamont-Doherty Earth Observatory of Columbia University, Palisades NY. The PhilEx Philippine Chief Scientist is Cesar Villanoy of the Marine Science Institute, University of the Philippines, Diliman, Quezon City 1101.

Fluctuations of circulation and ocean stratification, including small scale [<10 km] structures, within the Philippine archipelago are quite vigorous at tidal cycles, along/across the many passages and between seas. The research ship can make many important observations but it moves slowly relative to the tides, the 'spatial' structures we observe may actually be changes in time- the question remains: how do we know what is a spatial structure or a time fluctuation?

In order to answer this question, to quantitatively investigate the complex ocean circulation patterns a blend of methods is brought together into an 'experimental design', which includes ship based observations linked with time series data obtained from satellite, and from in situ moorings, Lagrangian platforms plus model output.

Observations spanning the time of the PhilEx field phase, 2007-2009, from the Exploratory cruise [June 2007] to the end of the IOP cruises [January-March, 2009] provide critical information about time fluctuations. They provide the connectivity between the bursts of ship based observations, essential for the development of an ocean model appropriate for the complex Philippine Archipelago region.

The Timeline of the observational component within Philippine waters is as follows:

The preliminary results of the Exploratory cruise are presented below; the Joint cruise design has reached an advanced stage. The design of the 2008 IOP cruise in the Mindoro Strait region depends to a large measure on the results of the exploratory cruise, and as time permits on the Joint cruise [noting it ends just before the first IOP]. The IOP cruise in 2009, Surigao focus will be designed after the 2008 IOP cruises.

III PhilEx Exploratory Cruise: Where we were and what we did-

[A] The cruise track are given in figure 1a-e

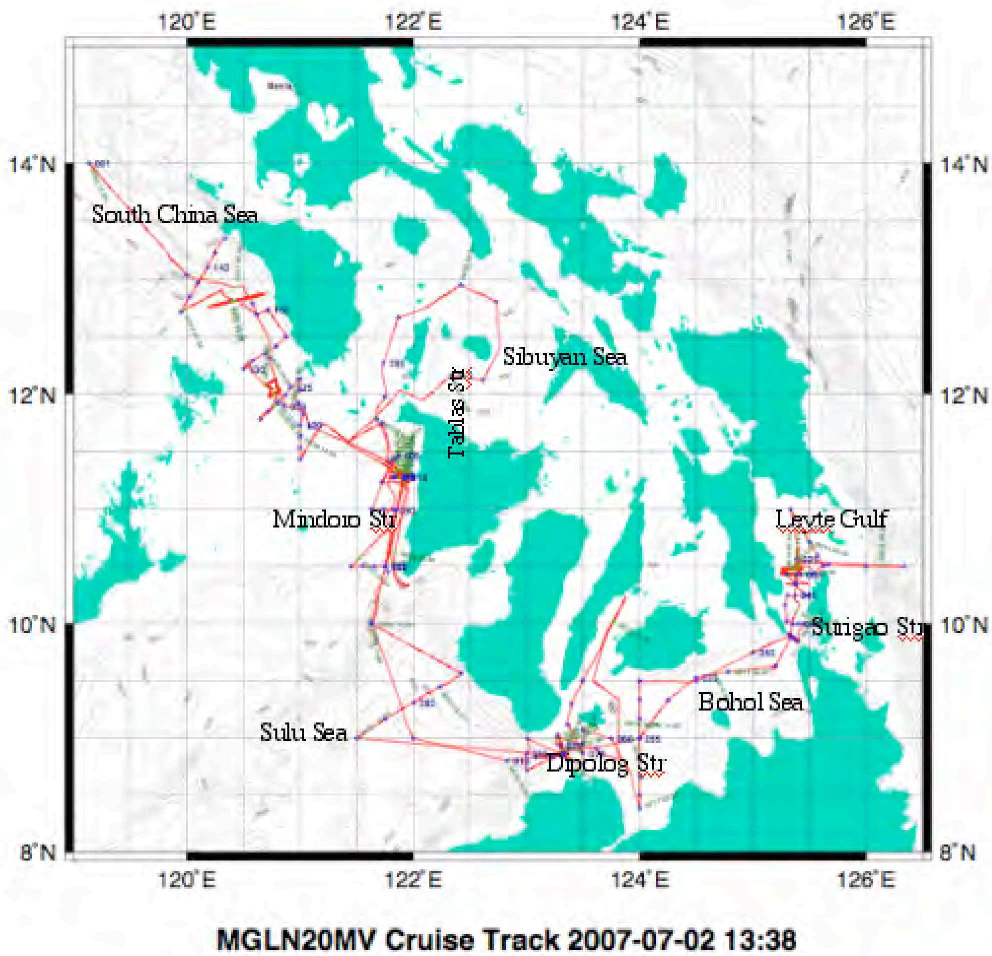


Fig. 1a. PhilEx Exploratory Track. Components of the track are given in Figure 1b to 1e. The CTD/LADCP station Table and maps [Figure 2] are given in Section B below .

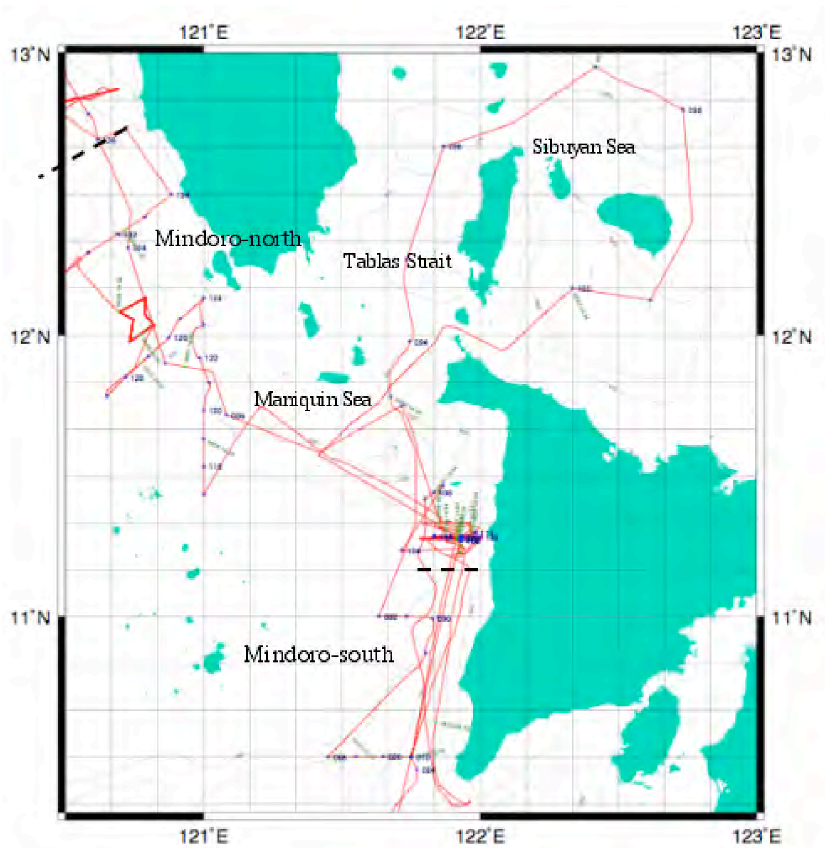


Figure 1b. The Mindoro [north & south], Tablas Strait and Sibuyan Sea. The dashed lines mark the position of the 1st and 2nd Mindoro tide resolving repeats, each about 24-25 hours in duration. Microstar experiments were carried out at these sites. The "hourglass" pattern near 12°N; 120°50'E marks a 3rd Mindoro tide repeat and Microstar deployment.

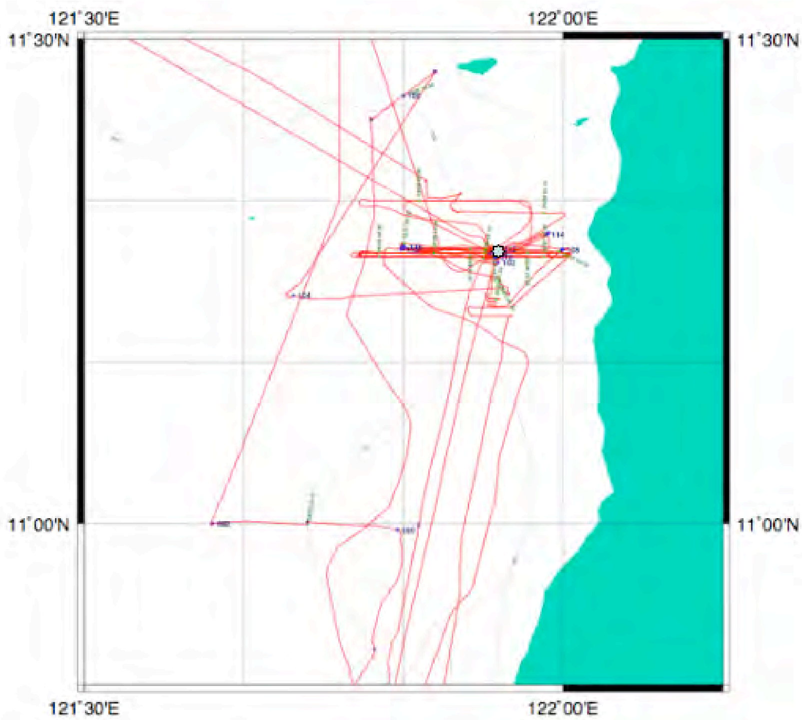


Figure 1c. Details of the Mindoro-south track. The blue 'star' marks the position of the ADCP mooring. The many red track lines at that latitude are those of the tidal repeat.

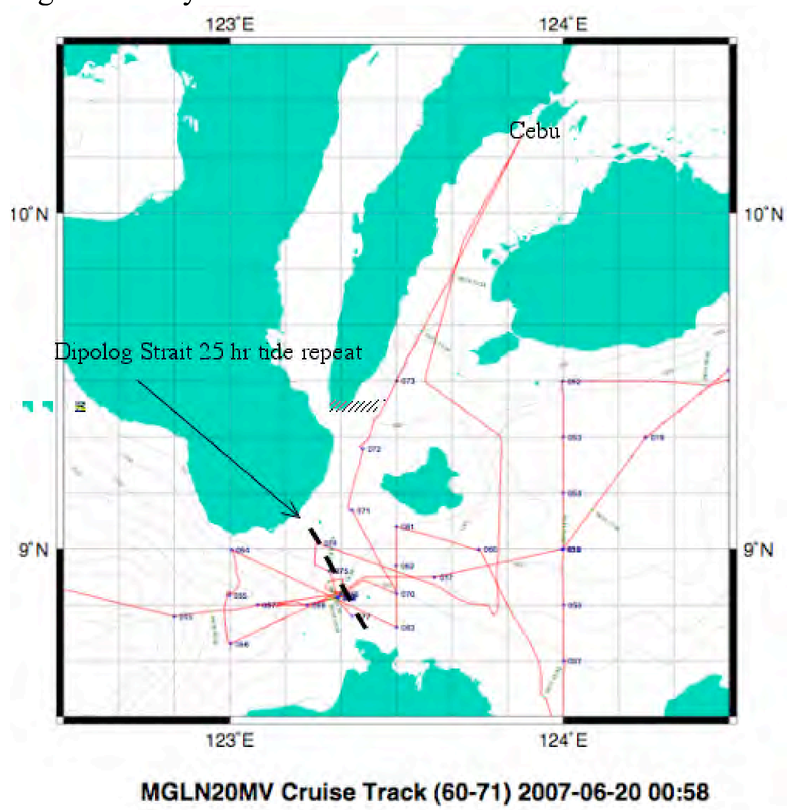


Figure 1d: Detailed view of the CTD stations and track for the Dipolog survey.

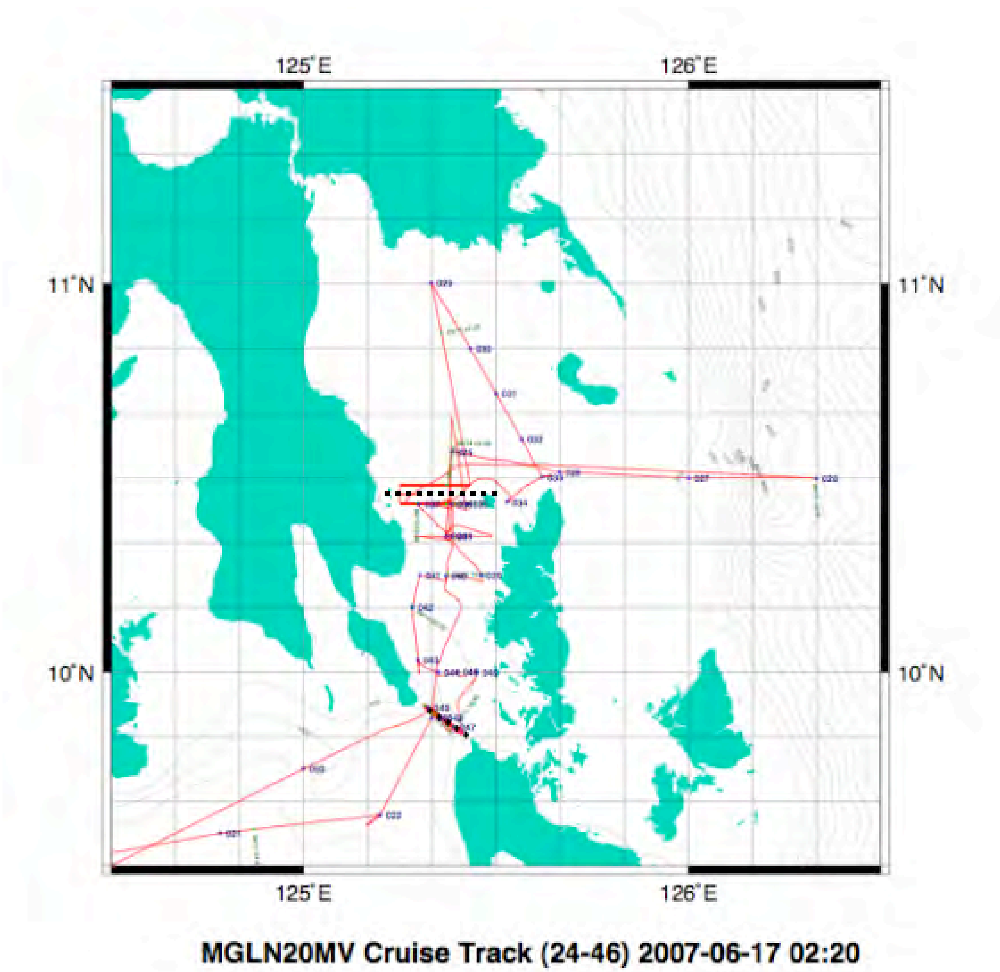


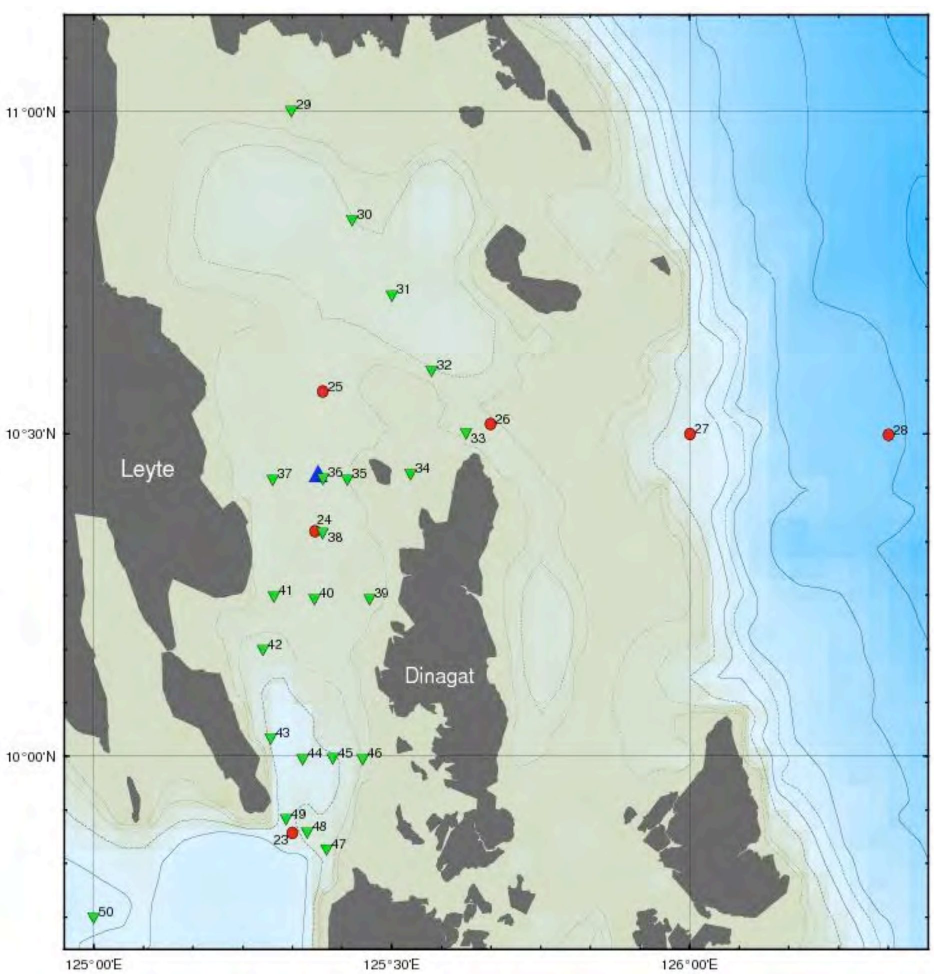
Figure 1e Detailed view of the CTD stations and track for the Surigao survey. The dashed black lines denote the position of the repeat hull ADCP tidal resolving sections: 25 hour tide resolving repeat was done at the northern Surigao near 10°25'N; and a 13 hour repeat at the southern entrance to Surigao neat 9°52'N.

[B] CTD/LADCP Table and Maps.

Figure 2 is embedded within the Table listings. The figure 2 symbols are arranged by time: 6 to 12 June: solid Red circles; 13-18 June: green triangles; 19 June - 2 July: Blue stars. Occasionally stations from different weeks are in same place blurring the symbol shapes. The large Blue triangles show positions of the current measuring [ADCP] moorings.

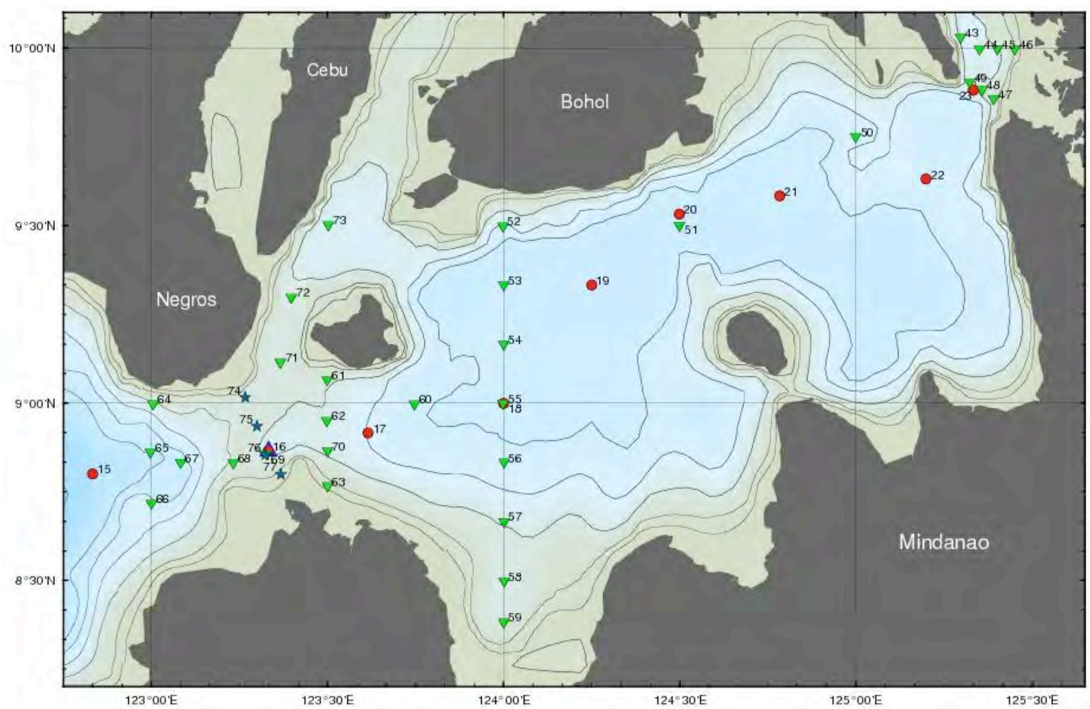
sta	lat (N)	lon (E)	yyyy/mm/dd	hh:mm	depth	dab	comments
1	14 0.00	119 8.00	2007/06/06	13:29	*5000*	*3019*	5 sa samples
2	13 2.05	119 59.95	2007/06/06	22:21	*3678*	*1690*	6 sa samples
3	12 47.03	120 35.01	2007/06/07	04:32	944	46	3 sa samples
4	12 18.62	120 43.60	2007/06/07	09:07	1171	29	
5	11 54.02	120 51.68	2007/06/07	13:13	475	24	

6	11 42.99	121 4.94	2007/06/07	16:18	655	10	
7	11 45.03	121 43.02	2007/06/07	21:17	1105	29	1 sa sample
8	11 16.73	121 55.44	2007/06/08	03:30	581	10	
9	10 59.90	121 50.95	2007/06/08	06:12	822	9	
10	10 30.00	121 44.99	2007/06/08	10:11	1378	16	
11	11 16.49	121 55.75	2007/06/09	00:55	586	12	6 sa samples no LADCP data
12	11 16.51	121 55.73	2007/06/09	03:41	587	9	
13	10 0.00	121 38.00	2007/06/09	12:24	*3128*	*164*	6 sa samples
14	8 59.95	122 0.04	2007/06/09	19:56	*4389*	*1417*	6 sa samples
15	8 48.00	122 50.00	2007/06/10	03:24	2964	52	6 sa samples replace primary pump
16	8 51.98	123 19.91	2007/06/10	08:53	483	10	
17	8 54.93	123 36.88	2007/06/10	11:31	828	15	
18	8 59.98	123 59.98	2007/06/10	15:08	1553	10	5 sa samples
19	9 19.98	124 14.97	2007/06/10	19:25	1780	46	



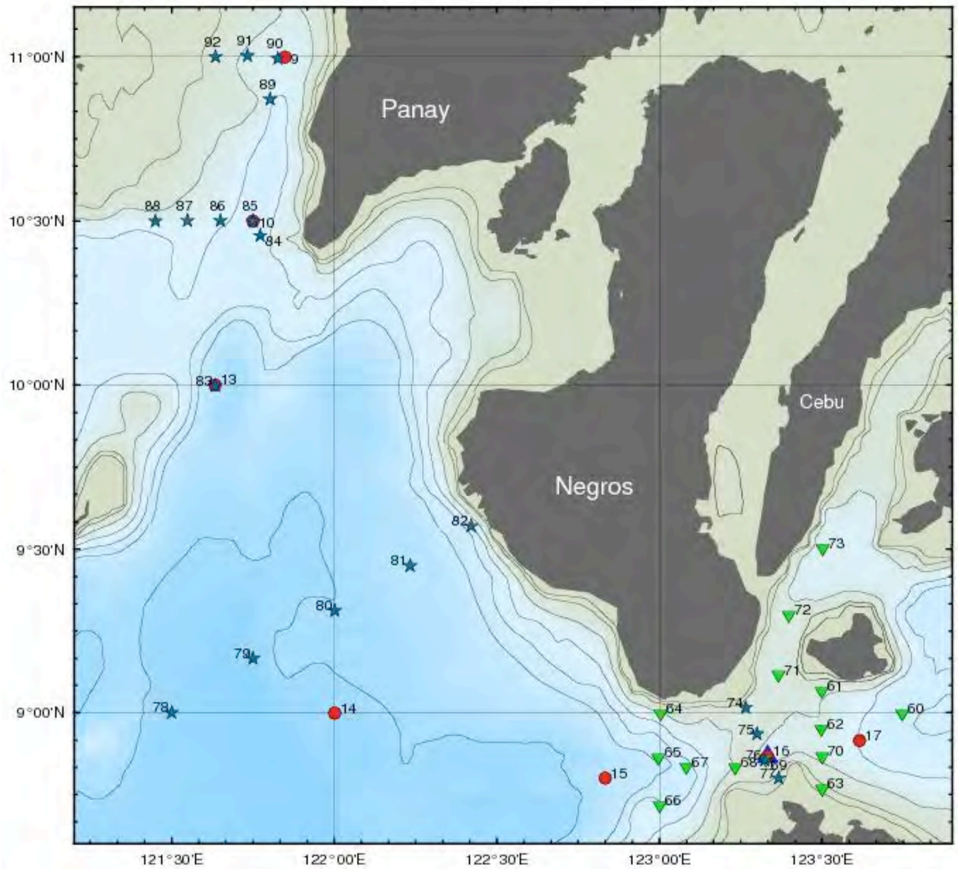
sta	lat (N)	lon (E)	yyyy/mm/dd	hh:mm	depth	dab	comments
20	9 31.95	124 29.89	2007/06/10	23:14	1813	32	
21	9 35.00	124 47.00	2007/06/11	02:37	1570	8	4 sa samples
22	9 37.93	125 11.93	2007/06/11	08:53	1473	11	
23	9 52.85	125 19.97	2007/06/11	12:03	682	55	
24	10 20.97	125 22.26	2007/06/11	22:00	203	20	
25	10 33.95	125 23.05	2007/06/12	04:31	137	12	

26	10 30.92	125 39.92	2007/06/12	06:32	135	10		
27	10 29.99	126 0.02	2007/06/12	08:58	935	8		
28	10 29.95	126 20.00	2007/06/12	11:45	*5988*	*3983*	8 sa samples	
29	11 0.14	125 19.88	2007/06/13	23:22	82	11		
30	10 50.00	125 26.00	2007/06/14	00:56	117	10		
31	10 43.00	125 30.01	2007/06/14	02:13	115	11		
32	10 36.00	125 34.00	2007/06/14	03:31	124	10		
33	10 30.22	125 37.46	2007/06/14	04:45	180	14		
34	10 26.40	125 31.87	2007/06/14	06:33	102	0	bottom hit. retermination.	
35	10 25.88	125 25.51	2007/06/14	11:43	191	11		
36	10 25.96	125 23.03	2007/06/14	12:56	172	10		
37	10 25.89	125 17.98	2007/06/14	14:06	119	10		
38	10 20.93	125 23.02	2007/06/14	15:26	187	12		
39	10 14.75	125 27.73	2007/06/14	16:50	104	18		
40	10 14.75	125 22.20	2007/06/14	18:05	189	13		
41	10 15.01	125 18.13	2007/06/14	19:18	153	10		
42	10 10.03	125 17.00	2007/06/14	20:37	1093	94		
43	10 1.79	125 17.79	2007/06/14	23:10	1314	189		
44	9 59.85	125 21.01	2007/06/15	00:53	715	43		
45	9 59.90	125 24.04	2007/06/15	02:08	325	5		
46	9 59.84	125 27.04	2007/06/15	03:05	221	12		
47	9 51.43	125 23.42	2007/06/15	19:17	409	20		
48	9 52.99	125 21.46	2007/06/15	20:21	330	76		
49	9 54.25	125 19.34	2007/06/15	21:08	671	68		
50	9 45.06	124 59.95	2007/06/15	23:28	1287	43	6 sa samples	
51	9 30.09	124 29.92	2007/06/16	03:35	1814	10	8 sa samples	
52	9 29.98	123 59.83	2007/06/16	07:45	944	38		
53	9 20.00	124 0.01	2007/06/16	09:32	1775	10		

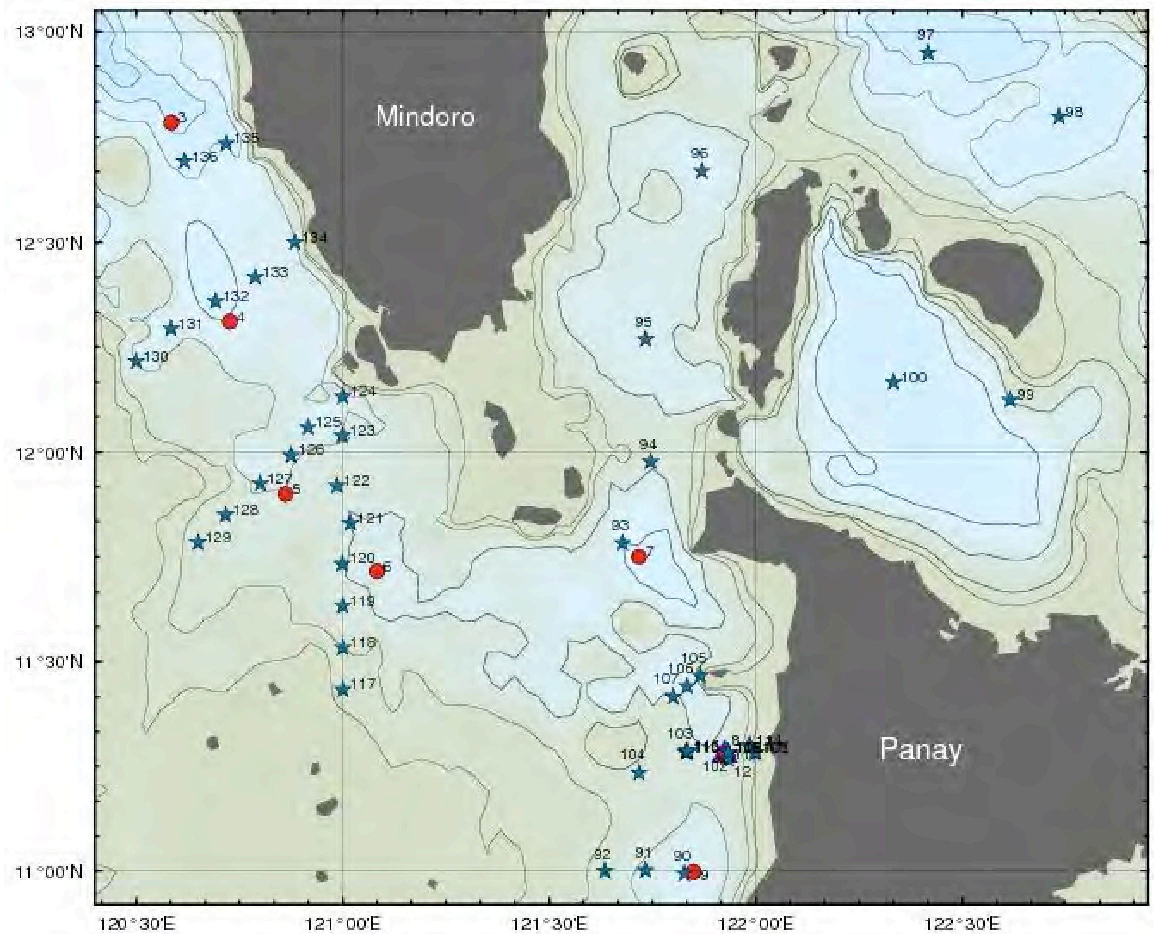


54	9 10.01	124 0.01	2007/06/16	12:54	1356	10		replace primary pump
55	9 0.00	123 59.86	2007/06/16	15:33	1553	13	6 sa samples	swap prim/sec pumps
56	8 50.04	124 0.05	2007/06/16	18:44	1501	17	2 sa samples	replace pumps, cables
57	8 40.01	124 0.06	2007/06/16	21:07	1367	17		
58	8 29.92	124 0.08	2007/06/16	23:34	1213	20	6 sa samples	
59	8 23.00	124 0.00	2007/06/17	01:35	1062	18		

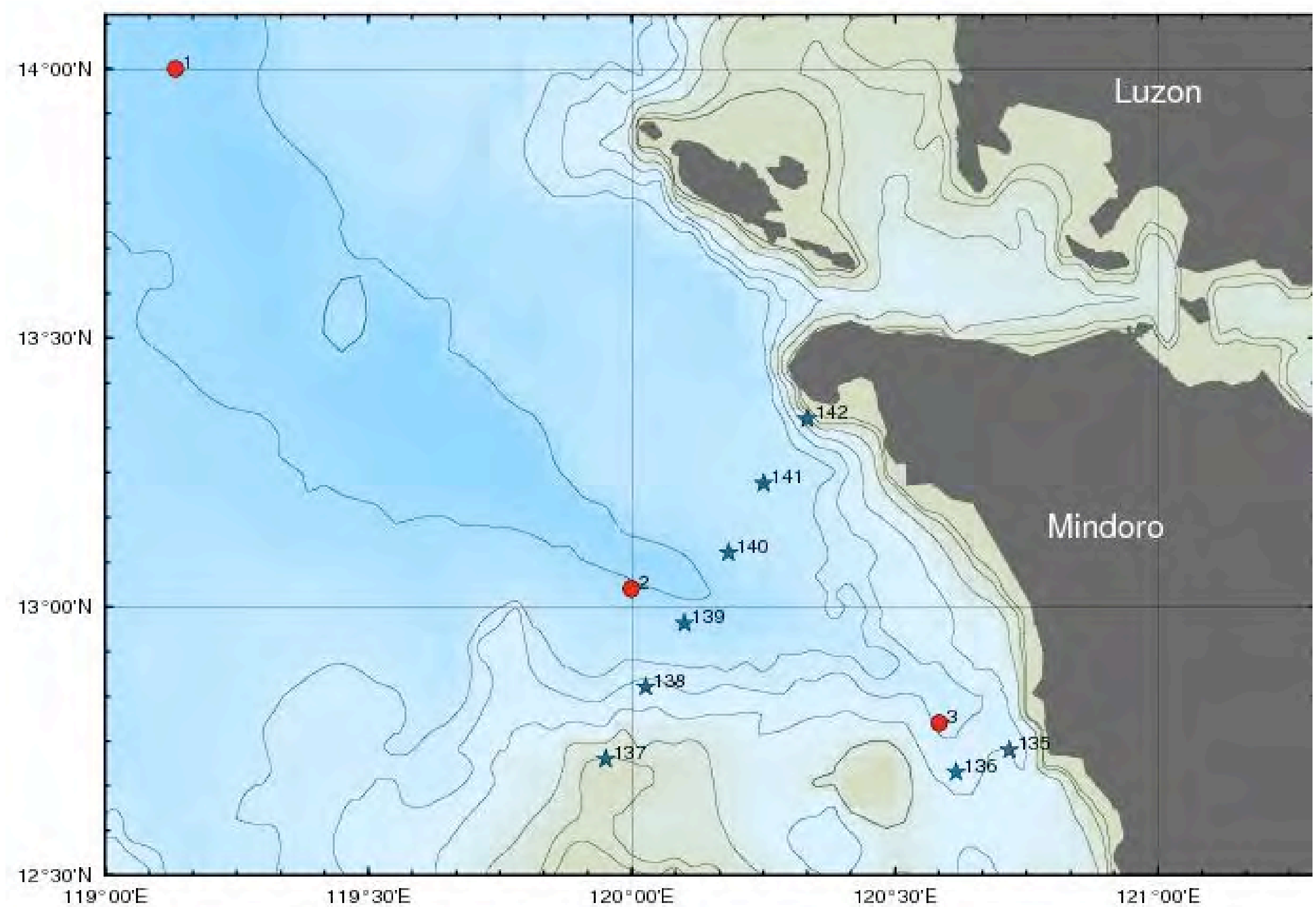
60	8 59.89	123 44.74	2007/06/17	06:27	1482	11	
61	9 4.01	123 29.92	2007/06/17	09:37	561	9	
62	8 57.05	123 29.87	2007/06/17	11:08	512	10	
63	8 46.01	123 30.00	2007/06/17	13:02	317	7	
64	8 59.88	123 0.22	2007/06/17	16:33	450	54	
65	8 51.72	122 59.80	2007/06/17	18:18	2163	54	6 sa samples
66	8 43.06	123 0.01	2007/06/17	21:13	1257	50	
67	8 50.03	123 4.96	2007/06/18	08:09	1781	8	
68	8 49.96	123 13.92	2007/06/18	11:15	842	9	
69	8 51.39	123 19.60	2007/06/18	12:58	454	15	



sta	lat (N)	lon (E)	yyyy/mm/dd	hh:mm	depth	dab	comments
70	8 52.01	123 30.01	2007/06/18	14:59	472	9	
71	9 6.95	123 21.94	2007/06/18	17:19	460	35	
72	9 17.93	123 23.82	2007/06/18	19:22	599	48	
73	9 30.13	123 30.10	2007/06/18	21:35	731	26	5 sa samples
74	9 0.97	123 15.94	2007/06/19	19:41	433	14	
75	8 56.12	123 17.98	2007/06/19	21:27	301	13	
76	8 51.32	123 19.41	2007/06/19	22:40	567	31	5 sa samples
77	8 47.99	123 22.00	2007/06/20	00:35	409	12	
78	9 0.01	121 30.02	2007/06/21	12:12	4539	92	8 sa samples
79	9 9.98	121 45.01	2007/06/21	17:18	4584	114	8 sa samples
80	9 18.73	122 0.11	2007/06/21	22:22	3759	95	6 sa samples
81	9 26.99	122 14.00	2007/06/22	02:51	3028	10	
82	9 34.21	122 25.26	2007/06/22	06:26	707	46	
83	9 59.97	121 38.03	2007/06/22	12:51	3172	71	
84	10 27.30	121 46.30	2007/06/22	18:15	1269	17	
85	10 30.01	121 44.98	2007/06/22	20:00	1378	16	
86	10 30.05	121 38.98	2007/06/22	21:53	876	12	
87	10 30.08	121 32.94	2007/06/22	23:26	811	16	
88	10 30.00	121 27.00	2007/06/23	01:06	987	12	
89	10 52.24	121 48.19	2007/06/23	04:50	934	19	6 sa samples



sta	lat (N)	lon (E)	yyyy/mm/dd	hh:mm	depth	dab	comments
90	10 59.61	121 49.61	2007/06/23	06:40	761	11	
91	11 0.13	121 43.99	2007/06/23	08:01	386	8	
92	11 0.00	121 38.05	2007/06/23	09:16	208	9	
93	11 46.97	121 40.61	2007/06/23	14:11	1002	11	
94	11 58.68	121 44.68	2007/06/23	16:33	372	13	
95	12 16.12	121 43.97	2007/06/23	18:55	654	19	
96	12 40.10	121 52.13	2007/06/23	22:10	596	11	6 sa samples
97	12 57.02	122 25.01	2007/06/24	02:21	1698	14	6 sa samples
98	12 47.91	122 44.05	2007/06/24	05:52	1500	13	
99	12 7.46	122 36.97	2007/06/24	11:46	1124	11	
100	12 10.02	122 20.00	2007/06/24	14:31	1343	11	6 sa samples
101	11 17.00	122 0.05	2007/06/25	03:55	631	6	
102	11 16.12	121 55.91	2007/06/25	05:10	574	7	
103	11 17.18	121 49.90	2007/06/25	06:32	394	11	
104	11 14.11	121 43.05	2007/06/25	11:08	236	9	
105	11 27.98	121 51.96	2007/06/25	13:22	451	27	
106	11 26.51	121 50.00	2007/06/25	14:22	1081	9	
107	11 25.02	121 47.96	2007/06/25	15:49	409	25	
108	11 16.94	121 59.86	2007/06/27	08:14	701	11	
109	11 17.03	121 55.97	2007/06/27	09:36	574	5	
110	11 16.98	121 49.86	2007/06/27	10:57	381	7	
111	11 18.02	121 59.11	2007/06/27	12:38	542	5	
112	11 17.00	121 56.00	2007/06/27	13:49	563	10	
113	11 17.03	121 50.03	2007/06/27	15:16	379	10	
114	11 17.84	121 58.96	2007/06/27	16:59	626	23	
115	11 16.99	121 56.02	2007/06/27	18:12	572	20	
116	11 17.19	121 50.05	2007/06/27	19:50	402	16	
117	11 26.00	120 59.99	2007/06/28	12:01	203	8	
118	11 32.02	121 0.01	2007/06/28	13:16	229	9	
119	11 38.00	120 59.97	2007/06/28	14:30	442	9	



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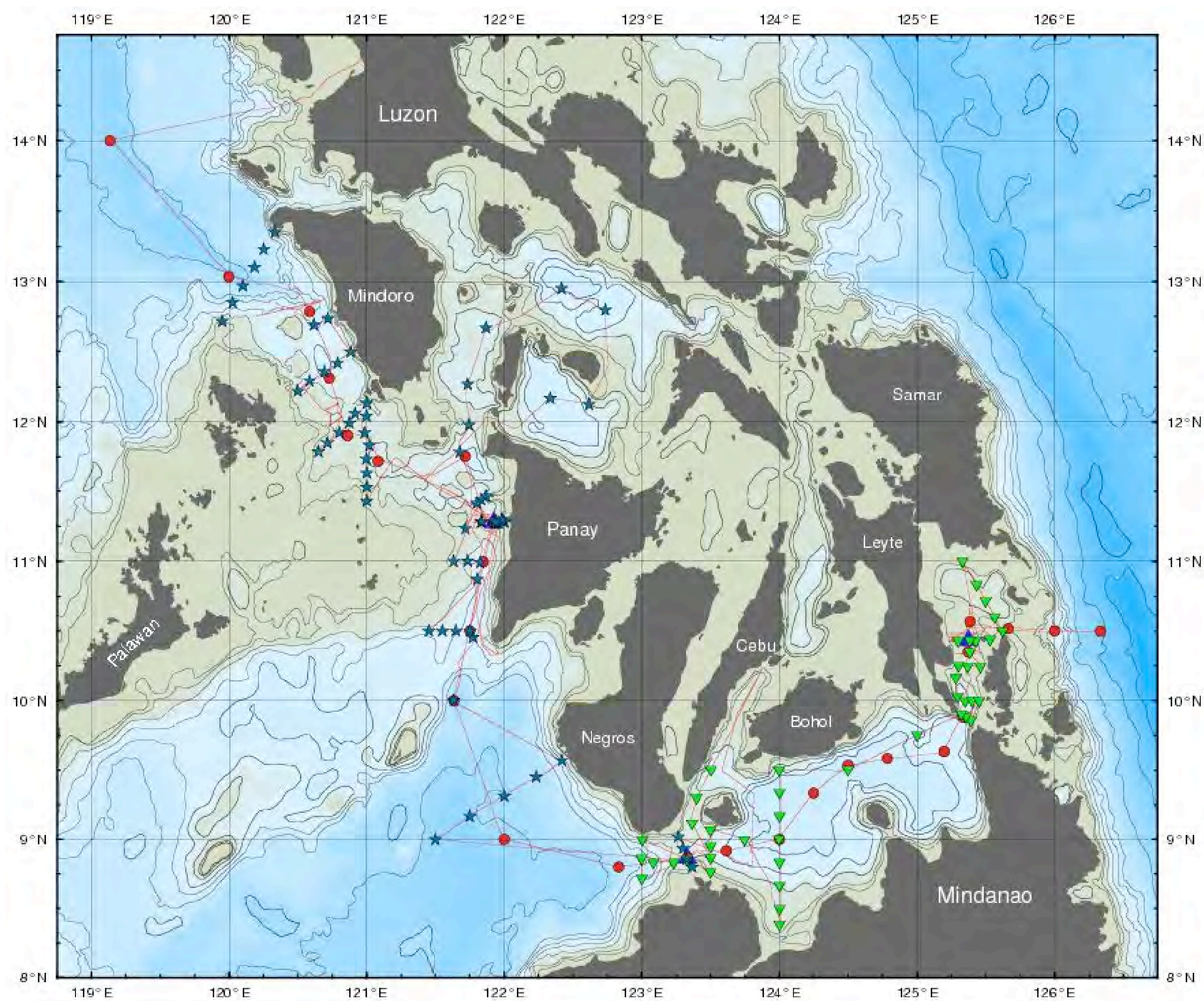
120	11 43.99	120 59.95	2007/06/28	15:48	343	35	
121	11 49.82	121 1.15	2007/06/28	17:19	459	24	
122	11 55.21	120 59.10	2007/06/28	18:40	455	20	
123	12 2.33	120 59.92	2007/06/28	20:17	470	44	3 sa samples
124	12 7.94	121 0.04	2007/06/28	21:39	548	10	3 sa samples
125	12 3.55	120 54.95	2007/06/28	23:03	457	8	
126	11 59.50	120 52.48	2007/06/29	00:17	553	14	6 sa samples
127	11 55.51	120 47.97	2007/06/29	01:46	525	12	
128	11 51.00	120 42.98	2007/06/29	03:05	350	11	
129	11 47.08	120 38.93	2007/06/29	04:14	273	10	
130	12 13.00	120 29.97	2007/06/30	10:18	504	9	
131	12 17.59	120 35.01	2007/06/30	11:43	771	10	
132	12 21.53	120 41.50	2007/06/30	13:23	1150	10	
133	12 25.04	120 47.29	2007/06/30	15:12	709	8	
134	12 29.93	120 53.01	2007/06/30	16:52	592	16	
135	12 44.04	120 43.06	2007/06/30	19:20	1200	45	
136	12 41.54	120 36.99	2007/06/30	21:13	884	12	
137	12 43.00	119 57.02	2007/07/02	02:50	272	16	
138	12 51.05	120 1.58	2007/07/02	04:17	1559	18	
139	12 58.17	120 6.01	2007/07/02	06:28	*3015*	*1504*	
140	13 6.09	120 11.03	2007/07/02	08:45	*2878*	*1363*	
141	13 13.75	120 15.07	2007/07/02	10:48	*2354*	*821*	
142	13 21.00	120 20.02	2007/07/02	13:06	336	9	



[C] Weather during the cruise: Winds were generally <10 kts and waves <0.5 m with infrequent rain showers. On the 26th June, with overcast to all horizons and heavy rain at times, some white capping, winds of 20 kts. The weather and sea conditions were reported 4 times per day to the PAGASA-DOST as required in the Consent to perform MSR within Philippine waters.

IV Listing of Exploratory Cruise Activities [chronological order]:

[A] Week of 6 June:

En route from the South China Sea to the western Pacific we took 28 CTD/LADCP stations.

We deployed a mooring on the southern Mindoro sill: lat/long @ 11° 16' N, 121°55' E, 9 June, 578-m, within the energetic sill overflow benthic layer.

We deployed the Surigao mooring on 12 June @ 10°26'N, 125°2'E in 169 meters of water.

Glider #1 and EM profiler #1 were deployed in the northern Sulu Sea at the southern entrance of the Mindoro Strait; Glider #1 @ 10°30'N, 121° 45'E; EM profiler @ 10°49'N. 121°49'E. Glider #2 was set out on 11 June @ 09°39'N, 125 12'E, in the eastern Bohol Sea where the Surigao through-flow enters the Bohol Sea. The 2nd EM profile had a malfunction and was not deployed.

En route was the normal suite of underway data collected by the Melville, including the kHz hull ADCP, which can reach as deep as 600-800 m and a 150 kHz narrowband system, 200-300 m. Two 25 hour repeat hull ADCP sections were obtained in Surigao [see figure 1e].

[B] Week of 13 June:

• Obtained CTD/LADCP stations from the Surigao to Dipolog, the Bohol sea including meridional section across Bohol Sea at 124°E.

• An EM-APEX profiler was deployed on 1522z 06/16/07 at 09 00.020N, 123 59.980E, to be recovered early on 20 June after we leave Cebu.

• We deployed the third ADCP mooring in Dipolog Strait on 18 June near at: 8° 51.921'N, 123° 19.970' E in 504 m, ~0.1 nm from CTD station 16. The mooring site falls between an Island to the ESE, Silino Island, and a reef to the WNW. The distance between the reef and the Island is ~6 nm. North and south of this gap the sea floor is slightly shallower. The Dipolog and Surigao moorings remain in place for recovery and redeployment during the Joint Cruise.

• The EM-APEX profiler deployed in southern entrance of Mindoro Strait has been found by a fisherman off of Panay. It has been recovered and will be sent to Manila for us to pick up when we return to Manila on 3 July.

• At Cebu we preformed a personnel transfer on June 19th. Joining the ship was Carter Ohlmann and Andrew Sybrandy who will oversee a drifter experiment in the Mindoro Strait. Bruce Huber and Olivia Cabrera left the ship. Directly after the Cebu stop we recover the EM profiler in western Bohol Sea, obtain the 25 hour tide resolving repeat section and a CTD/LADCP section across Dipolog Strait, then onto the Sulu Sea for a ~zonal section around 9.25°N.

[C] Week of 19 June:

• Completed the Dipolog Strait survey, including the tidal resolving 25 hour repeat at Dipolog Strait [race track: 8°50.34'N , 123°20.37'E to 9°02.28'N, 13°16.31'E]; a cross Strait CTD/LADCP along the same line.

• The recovered Bohol EM profiler was re-deployed on 24 June in the Mindoro Strait [2233z 06/24/07 11°34.398N. 121°24.986E. EM-Profiler #1636].

• CTD/LADCP in the eastern Sulu Sea to determine the sense of the basin scale circulation and into the southern Mindoro Strait to inspect the connectivity of the Mindoro with the Sulu circulation and stratification.

• Eight SVP [Surface Velocity Program, Argo tracked] drifters were deployed in Dipolog Strait and eastern Sulu Sea. Two were picked up [by one may assume] by fishermen, and one failed to work. The remaining SVP will be deployed in the northern Mindoro to track the spread of surface water into the South China Sea.

• A 10 Microstar fine scale array [~100 m separation] was carried out on 25 June ran quite smoothly [indication of anticyclonic shear, see Appendix B].

• Upon completion of the CTD/LADCP section , stations 105-107, within a constriction near 11°25'N at mid-night 25 June, we head south to the malfunctioning glider off the southern tip of Panay for retrieval in the morning light. *[Snagged from the Melville and brought aboard the ship at 0036z 06/26/07 10 19.833N. 121 57.071E]*. We then returned to the mooring latitude 11°17'N for a larger scale [1 km] microstar experiment; 25 hour tide resolving line; rotation of the ADCP mooring; additional CTD/LADCP stations.

[D] **Week of 26 June to cruise end on 3 July:**

• Tidal resolving repeat at two lines cross channel lines were performed in the Mindoro Strait region [figures 1b and 1c]. The Mindoro south line, 25 hours, at the mooring latitude, from 11°17'N; a Mindoro north line just north of Apo Reef, the largest of the reefs in the Strait, for ~23 hours [*we aimed for 24 hours, but the ever diminishing cruise* *time argued for breaking away from the repeat line after 23 hours, near the position at which we began the repeat lines*]. This line was positioned to investigating the interaction of Apo reef with the strong northward flow surface layer flow. A special 24 hour repeat was performed in an hourglass shape near 12°N in Mindoro north to investigate reef-circulation interaction at a smaller reef.

• The EM profiler #1636 deployed at 2233z 06/24/07 11°34.398N. 121°24.986E, was recovered 28 June in the Mindoro Strait ~0300z, 11 41.5098 N 121 18.9701 E.

• On the morning of 28 June the Mindoro ADCP mooring was recovered [0635L], data downloaded, and redeployed at same site. Anchor drop at 0050z, 28 June 07, triangulated position: 11°16.6438'N 121°55.4630'E. The mooring position is in a ~600 m deep valley connecting southern Mindoro to the Maniquin Sea, situated a bit "downhill of the shallowest sill, about 1.5 nm on Sulu Sea side of the sill. The seabeam map of the mooring region is given as Figure 3. [*Maniquin Sea: this the sea into which Mindoro north, Mindoro south and Tablas Straits are linked, making for an interesting interaction*]

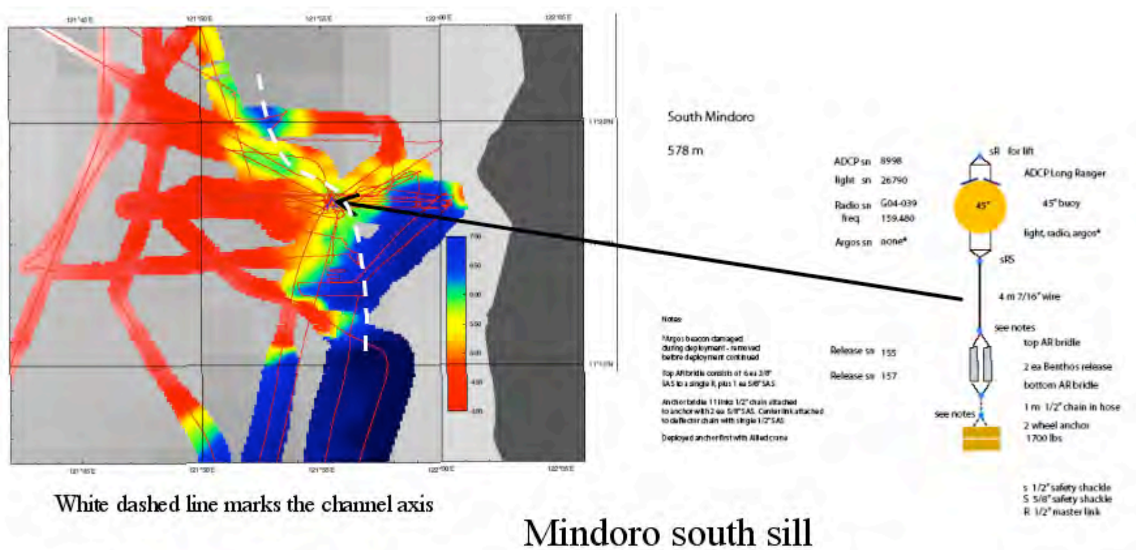


Figure 3. Seabeam map and Mindoro mooring location and configuration.

• CTD/LADCP array in the eastern Sulu Sea to determine the sense of the basin scale circulation and into the southern Mindoro Strait stratification and circulation including Mindoro south connectivity with the Sulu Sea and Mindoro north and Tablas Strait. The CTD/LADCP array in this phase of the observational program consisted of many cross channel sections, the last of which is across the northern boundary of Mindoro north, where it meets the South China Sea.

• Three arrays of Microstar 10 to 12 drifters spaced at ~1 km were carried out in conjunction with the Mindoro tidal repeat sections [including the hourglass one]. A fine scale array at ~100 m spacing was deployed in the mooring area for a 6 hour experiment. The operating microstars deployed in Mindoro north were not recovered but left to trace the surface flow patterns of the Mindoro water entering into the South China Sea, with their 3 to 4 days of remaining battery left.

V Preliminary Scientific Results of the PhilEx Exploratory Cruise

[A] Bohol [Mindanao] **Sea** [see- Summary Schematic of the mean circulation pattern from Dipolog to Leyte Gulf, Fig. 10]:

• The Bohol Sea appears to have an estuary circulation pattern, with surface flowing westward in the upper 100 m over an overturning cell of Sulu water drawn into the Bohol Sea through the Dipolog Strait. The westward flowing surface water is drawn from the Surigao Strait and represents a mix of Pacific water and entrained subsurface Bohol Sea water.

• The salinity-minimum [S-min] entering the Bohol Sea through Dipolog shifts to greater depth and its core to higher density on proceeding eastward, a likely sign of entrainment into the westward flowing surface layer out of Leyte Gulf. In the western Bohol Sea it is 24°C, 34.29, 100 m, 23.1 sigma-0; at the southern entrance to Surigao Strait [eastern Bohol Sea] the S-min is at 18°C, 34.42, 175 m, 26.0 sigma-0. This appears to be classical estuarine type circulation, with the Pacific water analogous to the “River” water, and the Sulu Sea water analogous to the “Ocean” water.

• I suspect that the S-min near 150 m within the Bohol Sea is derived from winter cooling of low salinity surface water off the coast of China. The S-min falls in the same density range as the S-max of the subtropical North Pacific, which enters the South China Sea via Luzon Strait. The generation of the low salinity surface water off the coast of China must be fairly robust to counter the Pacific S-max.

• The 124°E section within the Bohol Sea reveals a counter-clockwise gyre, ~20 cm/s surface speeds. With the Surigao surface layer tracking along the northern Bohol Sea towards Dipolog Strait. Water masses and hull ADCP indicate that the surface water flow from Surigao is funneled into Dipolog between Siquijor and Negros Islands, which is called Bohol Strait, ~400 m deep. Within this passage the subsurface S-min drawn into the Bohol Sea from the Sulu Sea via Dipolog is much attenuated, as expected- this S-min water tracks eastward south of Siquijor. Current profile within Bohol Strait is generally less than 20 cm/s, net transport is low [0.1 or 0.2 Sv, this is close to the suspected net intake of Pacific water via Surigao].

• At depths, below ~200 m within the Bohol Sea there is a deep reaching estuarine type flow pattern, with the bottom ventilation derived from gravity current spill-over in Dipolog Strait. The null depth, where the westward flow from Dipolog is separated from the deeper eastward flow, in keeping with the estuary patterns is 600 to 1000 m.

[B] Surigao Strait

• The Surigao Strait survey was conducted during the spring tide. The spring tide signal, primary a diurnal character, was a dominant presence. Tidal flow in the upper ~80 m towards the Bohol Sea, speeds of 3 kts flood tide, Pacific bound at ~0.5 kt in slack tide. At mooring site the temperature/salinity profiles show lots of small scale [high frequency] reversals and steps in the T/S profiles, indicative of active microstructure and mixing as the Pacific water passes over the regional subsurface water. The mooring was placed in 168 m of water in the passage between Dinagot Island and Leytes Island. To the north, before the open Pacific is met, there is a broad shallow embayment, with typical depths of <130 m, and a very homogenous water column [e.g. station 26].

• Thermohaline stratification feeding into Surigao Strait: In the Leytes Gulf, the shallow embayment north of Surigao Strait, the water column is composed of Pacific surface water drawn from the 0-50 m levels from the adjacent western Pacific. This water mixes downward to the ~100 m floor of the Gulf, before passing through the Surigao Strait. The mixture includes freshwater brought into the region by inflow along the bottom of the Surigao Strait of lower salinity lower oxygen water from the Bohol Sea.

• Within Surigao Strait the mean [sub-tidal frequency] speed at ~50 m during the tidal resolving repeat [barotropic] is 44 cm/sec southward, leading to an estimate of the southward transport over the diurnal cycle of ~0.4 Sv [Sv = 10^6 m^3/s]. It is possible that there is some return mean flow east of Hinunan Island, the ~90 m deep channel in that passage is narrow, about 3 km, but it could reach 0.1 Sv. Additionally, not all of the 0.4 Sv need be derived from the Pacific: within the northern entrance of Surigao Strait is bottom water of relatively low salinity derived from the Bohol Sea. This water may be entrained into the surface layer and compose part of the 0.4 Sv. *"Guess": a net Pacific throughflow into the Bohol Sea of 0.2 to 0.3 Sv is likely.*

[C] Dipolog Strait, the western passage to Bohol Sea [see- Summary Schematic of the mean circulation pattern from Dipolog to Leyte Gulf, Fig. 10]:

• Station 16 reveals strong eastward flow within the benthic layer lower ~80 m, max speeds near bottom of 40-50 cm/s [est. transport ~0.2 Sv]. Station 17 shows this bottom intensified flow near 800 m. Station 69 in the same place as station 16, also shows the benthic layer overflow, but less energetic, with lower 50 m speeds towards the Bohol Sea of <10 cm/s. Station 76 a bit 'downhill' from the sill, also showed reduced benthic layer flow. It is likely that the rate of the overflow into the Bohol Sea is modulated by tides or perhaps mesoscale variability at the mouth of the Dipolog Strait.

• Dipolog Strait surface [0-100 m] throughflow is towards SW across whole extent of the strait. A tidal signal superimposed, but mean flow seems robust. Subsurface flow [100-250 m] is into the Bohol Sea. This pattern is supported by the 25-hour tidal resolving data [Figure 4 from the Hull ADCP]. The surface layer flow into the Sulu has a northern and a southern axis. This pattern could it be a projection of a split in the outflow induced by Siquijor Island: the outflow via Dipolog Strait has two approach routes from the east- 1. Bohol Strait between Siquijor and Negros Islands and 2. south of Siguijor Island. An estimate of the transports from the hull ADCP is as follows: 0.3 Sv surface layer flow from Bohol Sea to Sulu Sea; 0.2 Sv subsurface layer flow from Sulu to Bohol, with a net outflow of 0.1 Sv. Of course the errors is large [for all sorts of reasons], but I think this is the ‘ball-park’ throughflow value.

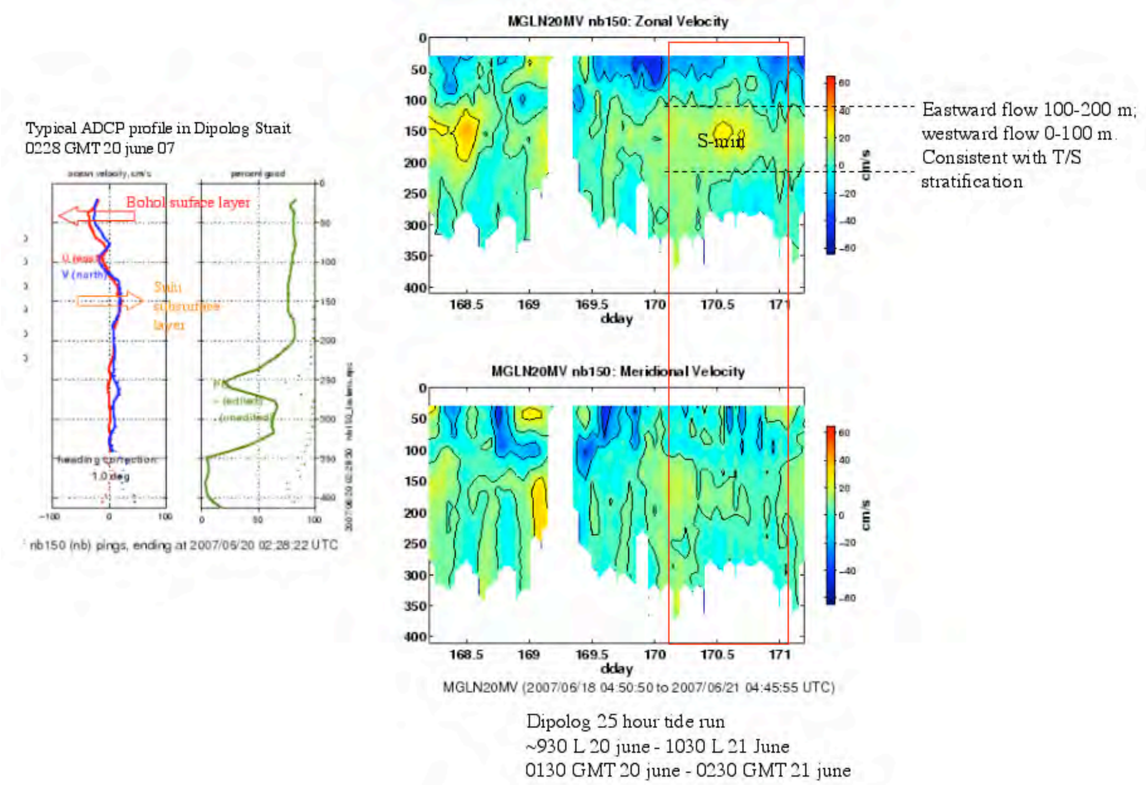


Figure 4 zonal and meridional speeds in Dipolog Strait during the 25 hour tide resolving repeat line. The Red Box delineates the time of the tide repeat lines.

[D] Sulu Sea

• The Sulu Sea water column below ~1200 m, is nearly isothermal at ~9.8°C with increasing salinity and decreasing oxygen to the sea floor, ~4500 m. The reduced oxygen is easy to explain- oxidation of organics, but the salinity explanation requires some imagination. The density profile has an exponential form from ~1000 m to the sea floor, which may be considered as the standard overflow profile within an isolated basin. The benthic density observed at station 8, near the southern sill of Mindoro Strait, is sufficient high to reach the bottom of Sulu. However, its salinity and temperature are lower than the bottom water in Sulu. Entrainment of Sulu water into the overflow from the 600-700 m level would dilute the overflow characteristics, making for less dense, saltier and warmer. I conclude that deep reaching ventilation continues, perhaps modulated by the baroclinic tide. The strange form [an almost isothermal layer, coupled with a salinity and oxygen gradient] of the T/S below 1200 meters may be explained as follows: While geothermal heating is likely a factor in governing the deep water profile within the Sulu Sea, the observed profile below 1200 m may best be explained by variable T/S properties of the overflow of South China Sea water via the Mindoro. When SCS pycnocline is shallower as during the great El Niño episode of 1997, the overflow into the Sulu would have been cooler and saltier [denser]. Geothermal heating, most likely from the side walls of the basin [lots of volcanic Islands and shallow ridges in the western Sulu Sea to provide such a source], may have warmed the overflow water, but not induced a deep homogeneous layer, as would be expected if the geothermal heat is derived from the deepest sea floor. At station #4 just south of the Apo Reef region ~12°40'N, has a thermometric depth of ~800 m, with bottom water equal to the saline bottom water in the Sulu Sea. If this water gained access to the Sulu Sea across what are most likely shallower sills between station 4 and the Sulu Sea it would deliver the needed overflow water to explain the salty bottom water in the Sulu Sea. The "coolness" would then have to be removed by the side wall geothermal heating. So bottom line: continued deep ventilation, punctuated by occasional blasts of more salinity overflow, though not enough to cause temporary stagnation, with side wall geothermal heating [rather than deep central basin geothermal warming].

• Surface vs. subsurface gyres [Figure 5]: The hull and LADCP data as well as the T/S stratification reveal a surface flow pattern in eastern Sulu that depicts a basin scale clockwise, anticyclonic pattern. The surface water export via Mindoro into the South China Sea is derived from the western Sulu Sea, from the region between Palawan and Tubbataha Reef/Cagayan Island, with closure in the passage west of Tubbataha Reef. This flow pattern does not extend into the deep water. At 100 m the sense of the gyre changes taking on a counterclockwise, cyclonic flow pattern. It is this circulation layer that advects the subsurface s-min that enters the Bohol Sea via Dipolog Strait. The subsurface flow that carries the s-min water into the Sulu Sea via Mindoro, turns westward upon entering the Sulu Sea to trace along the Sulu in a cyclonic sense. The inflow [SCS>Sulu] near 200 m found in early June within Mindoro Strait was not apparent in late June, though the dense water overflow into the depths of the Sulu across the south Mindoro sill was active in both periods. If this is the mark of the maturing of the summer monsoon or higher frequency forcing is not yet known.

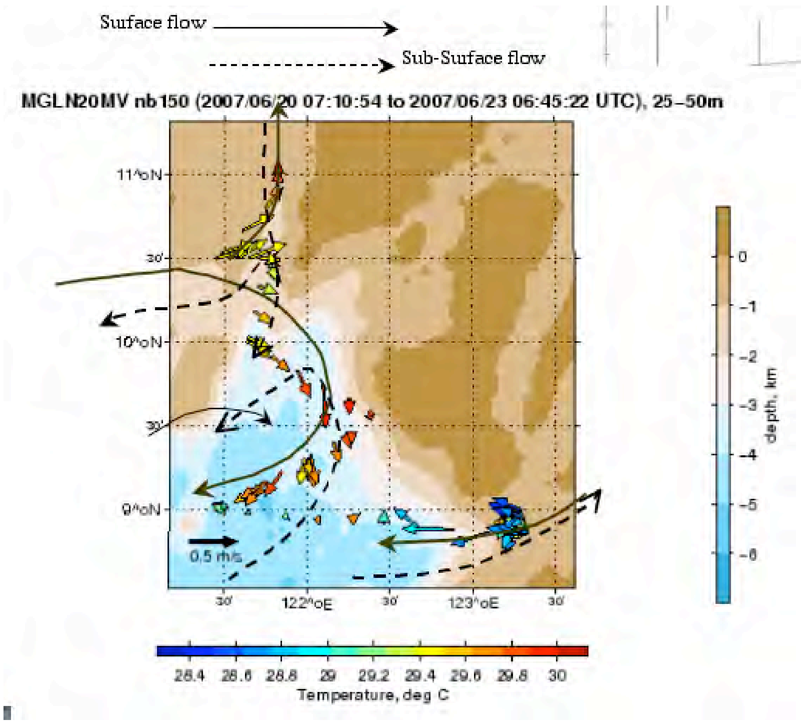


Figure 5 Hull ADCP and circulation pattern in Sulu Sea as revealed by ADCP and T/S stratification. The solid arrows are current at 25-50 m, color coded for temperature. The water warms within the Sulu Sea, from the 'cool' westward flow from Dipolog to the export to the South China Sea, warmest in the recirculation limb in the eastern Sulu [neglecting the possible inflow of surface water from the Sulawesi Sea via the Sibutu Passage of the Sulu Archipelago]. The subsurface 150-250 m flow pattern is shown by the dashed arrows. The inflow [SCS>Sulu] near 200 m found in early June within Mindoro Strait was not apparent in late June, though the dense water overflow into the depths of the Sulu across the south Mindoro sill was active in both periods.

[E] Mindoro Strait [see- Summary Schematic of the mean circulation pattern within Mindoro Strait, Fig. 11]:

• The Surface Layer: In early June the surface layer, upper 100 m, was flowing towards the South China Sea (SCS) at <10 cm/s in Mindoro south, ~20 cm/s in Mindoro north, but in late June when we returned to Mindoro Strait the surface layer flow towards the SCS increased to ~30 cm/s in Mindoro south and ~50 cm/s in Mindoro north. There are also indications of increased SCS stratification, and as noted below there may also be additional outflow of subsurface s-max water from the Sibuyan Sea via Tablas in late June.

• The Subsurface Layer: In early June we observed a SCS to Sulu Sea, southward flow below 200 m within Mindoro Strait of ~10 cm/s. In late June Sulu bound flow occurs only in the benthic layer overflow ~500 m. At the mooring site near 11°17'N the overflow was near 50 cm/sec [see comment on the mooring time series below]. Between the upper 200 m and the benthic layer at the sill the flow is weak, usually below 20 cm/sec though peaks of 30 cm/sec occur, but towards the north. Might we in June have observed the transition of subsurface flow into the summer monsoon condition? Or might it be other remote forcing effects? The IOP can investigate.

• Within the southern Mindoro Strait there is a slight relaxation of the temperature profile near 13°C near 300 m. This layer is marked by a local oxygen-min and salinity-min. This water type is most pronounced in the Sulu Sea, and absent in the northern Mindoro. It can be traced to outflow from the Bohol Sea, via Dipolog Strait. The ADCP data from the late June occupation indicates northward flow at this level in the southern Mindoro Strait. During the initial pass thru the Mindoro in early June, the flow was southward and the 13°C oxy-min, S-min was absent. The ADCP mooring also indicates more common southward flow at this level in early June than in late June. *Speculation*: The 13°C Sulu water invades the southern Mindoro as the flow subsurface flow from the SCS relaxes, in what is likely a onset of the summer monsoon effect. One may assume that this layer will creep northward as the summer monsoon continues. If true, then the monsoon effect on circulation affects the subsurface. Does the subsurface cyclonic flow [see Sulu Sea results section] in the Sulu Sea also reverse in the summer monsoon?

• There is very vigorous [bottom intensified] overflow of South China Sea water into the Sulu Sea across the southern sill in Mindoro Strait, near 11°17'N; 121°55'E, depth ~580 m. This is where the South Mindoro mooring was placed. Navigation maps and data collected on cruise show that this is the shallowest sill in the southern Mindoro Strait [south of Tablas Strait]. Stations 5 and 6 [average ~11°54'N, 121°E, see figure 1] straddle the northern Mindoro sill. Station 6 shows some bottom intensified flow of ~40 cm/s near 500-600 m suggesting it is downstream, spill-over side of the sill. In the northern segment of Mindoro Strait, between stations 5 and 6 the thermometric depth is about 460 m, but the bathy data suggest a complex 'braided' arrangement of channels, so maybe the real sill is deeper. Thermometric deduced sill depth, a classical oceanographic procedure in which T/S stratification on either side of a sill is compared, is shallower than real sill depth, assuming the flow is not purely laminar as mixing within the sill tends to lead to a warmer overflow product.

• Mindoro to Sulu Gravity Current: CTD/LADCP # 8 and its repeat #12 show nearly the same profile: a ~100 m thick benthic [well mixed] layer with southward speeds of 1 to 2 kts, amounting to a transport of ~0.5 Sv. Near 600 m in the Sulu Sea [station 10, see fig 1] at the southern entrance to the Mindoro Strait, there is a jet [~15-20 cm/s] of water flow towards the Mindoro Strait: possible induced by entrainment of ambient water by the sill overflow gravity current. The well mixed benthic layer is an example of how actual sill depths are greater than thermometric sill depths. As mentioned in the previous report in Mindoro Strait, at depths above the benthic gravity current, the flow is mostly towards the South China Sea in the upper 150 m; towards the Sulu Sea below 200 m.

• Cross Mindoro Strait Shear, dv/dx:

Mindoro south: CTD/LADCP across Mindoro Strait at the mooring latitude 11°17'N, the tide resolving repeat [Figure 6] and the drift of the microstar array, reveal an east - west structure of the along-axis flow, with stronger northward flow on the west side. The amplitude of west-east asymmetry in the surface layer is ~ 20 to 30 cm/s, ~ 40 cm/s at the west, ~10 cm/s on the east boundary. On the east side there is often a weak [0 to 10 cm/s] southward flow near 150-200 m. The western intensified northward flow of the upper 150 m reaches a maximum speed of ~60 cm/sec at around 90 m, not at the surface. A diurnal tidal barotropic current of ~10-15 cm/s is superimposed on the pattern. This asymmetry is also found at the three closely spaced cross channel CTD/LADCP stations at the mooring latitude, to the north near 11°25'N, and to the south near 11°00'N. The cross channel density gradient appears to be "geotropically" consistent with the along-axis flow pattern.

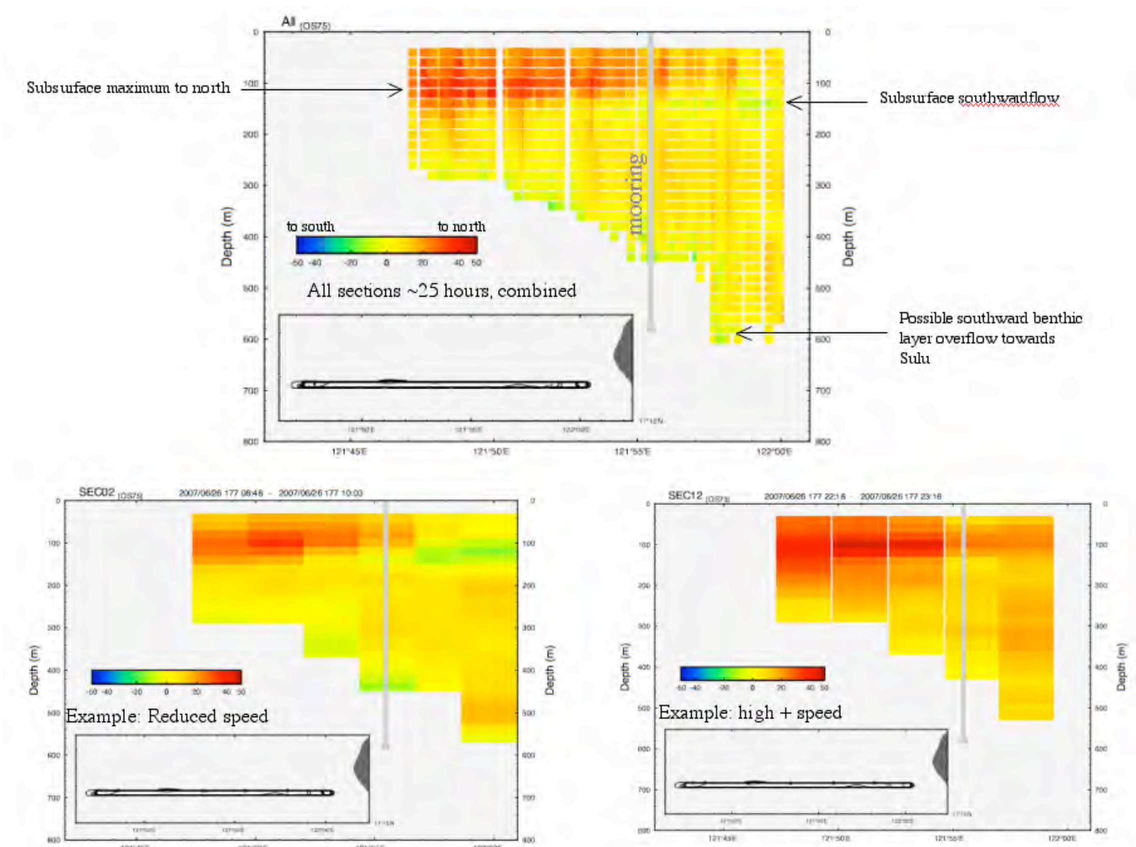


Figure 6. Meridional speeds across the latitude of the Mindoro south mooring, 11°17’N. Upper panel is an ensemble of all of the 18 sections over 25 hours. The lower panels are examples of sections that show weaker [left] and stronger [right] northward flow.

Mindoro north [Figure 7]: Here too the flow becomes western intensified, shortly after the inflow from the southeast adjusts to the Strait confines. A characteristic of Mindoro north are the many reefs, which act as obstacles to the flow. They may induce turbulence and wake features, and so I refer to them as “stirring rods”. Apo Reef is the giant one, and clearly has an effect on the northward flow observed in late June 2007 [see the Drifter Report, Appendix B].

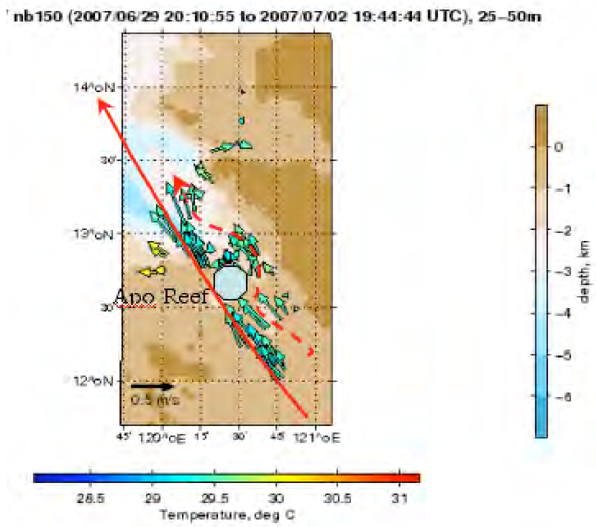


Fig. 7. Hull-ADCP 150 KHz measured flow, 25-50 m interval within Mindoro north.

• How well do the models capture the western intensification of the northward flow, and weak subsurface southward flow? Figure 8 shows examples provided by Shelley Riedlinger. It, as well as the HyCom 1/12 [pc Joe Metzger] and ROM model [pc Julia Levin] output while not perfect are encouraging.

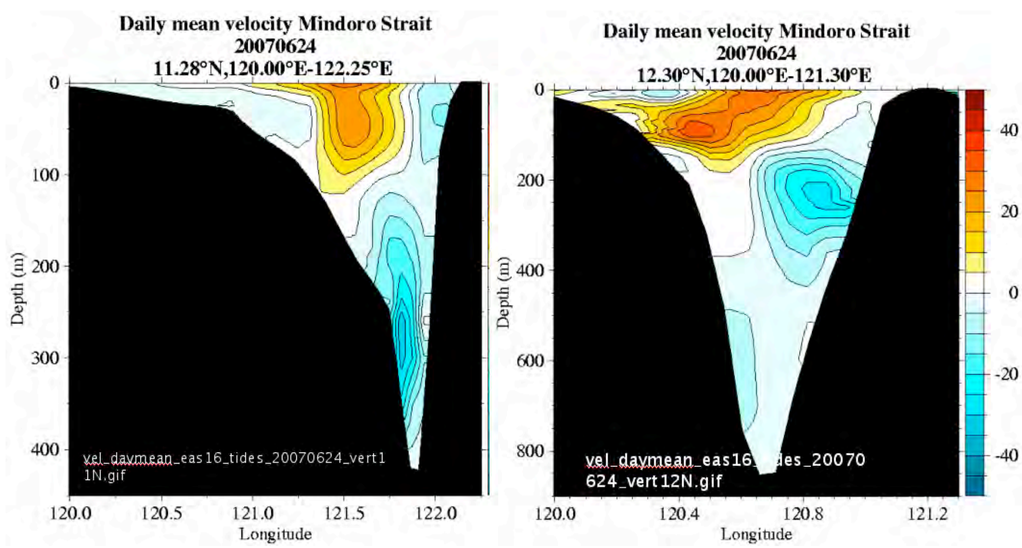


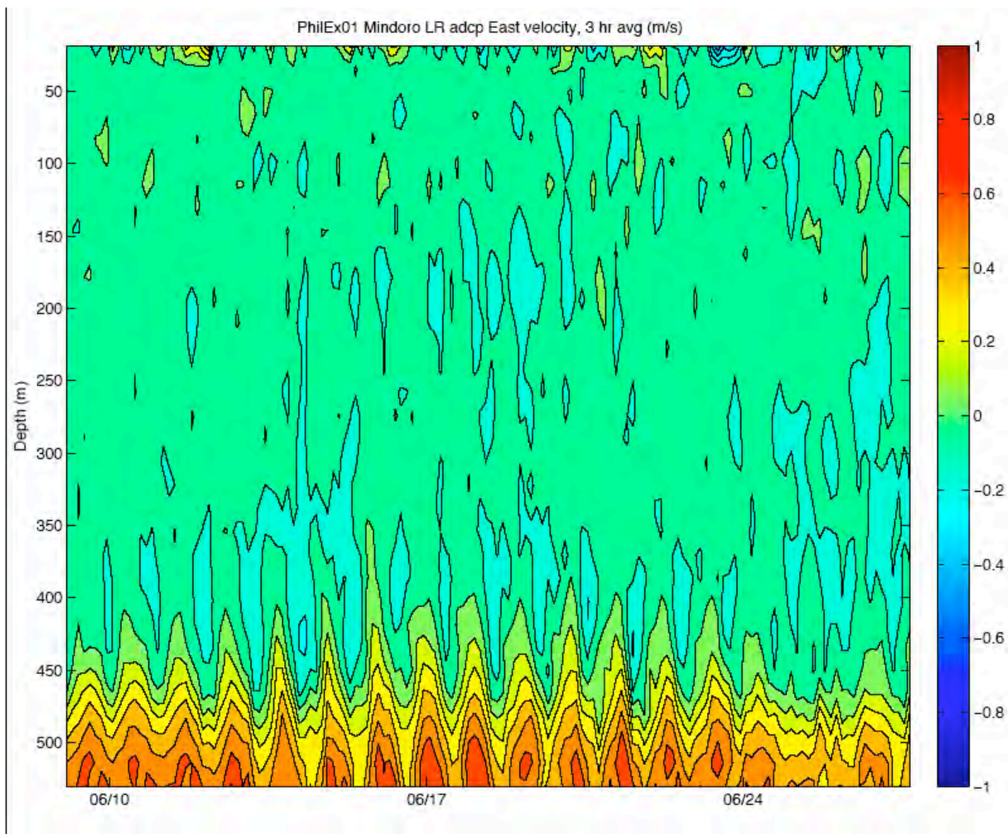
Fig. 8 Daily mean velocity within Mindoro Strait north and south, EAS16 model.

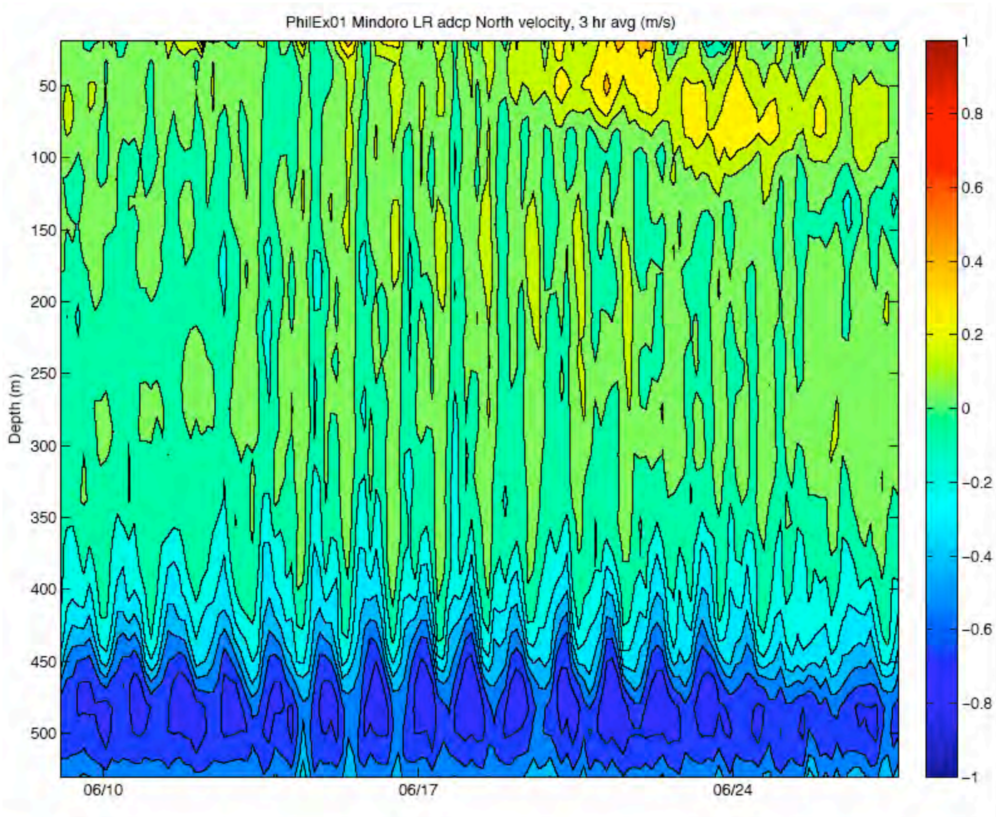
• Time Series, 8-27 June in Mindoro south [Figure 9]:

Clear tidal beat, with diurnal and fortnightly tidal overtones.

Southward flow increases during the deployment period [presumable as the summer monsoon sets-in], becoming subsurface ~23 June [SSS horizontal gradient?]. The flow from 150 to 350 m gets a bit weaker as June progresses.

The flow is meridional except within the benthic layer of the lower 100 m, where is consistently directed towards the southeast, the along-channel direction, see figure 3. The bottom intensified flow spills into the depths of the Sulu Sea. That the zonal component reaches a maximum at the sea floor, of ~70 cm/s, but the meridional flow is at a maximum ~50 m at ~ 80 cm/s [speed of ~ 2kts!], off the sea floor, may be more to do with deepening of the channeled flow's southern bank, than with bottom friction effects. Using the approximate average along channel speed of the lower 100 m of 0.7 m/sec, yields a spill-over transport of 0.25 Sv and a residence time for the deep Sulu Sea of ~50 years.





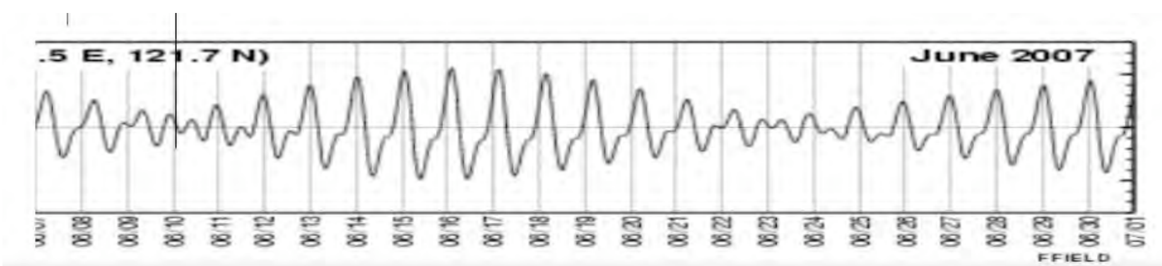


Figure 9. Zonal [upper panel] and meridional [lower panel] speeds recorded by the Mindoro ADCP mooring 11° 16.646' N 121° 55.456' E, ~mid-channel. Note the vigor of the benthic layer, also its SE direction, in contrast to the meridional flow in the rest of the water column. All show tidal signature. [prepared by B.A.Huber]

[F] Tablas Strait and Sibuyan Sea

• The Sibuyan Sea, a San Bernardino signature: The low salinity surface flow through Tablas Strait is towards the north, with likely export via Verde Island Passage. From ~80 to ~110 meters within the Sibuyan Sea basin north of Sibuyan Island, there is a salinity maximum, approaching 34.5, at a temperature of 25-28°C. The source of this water cannot be the South China Sea via Verde Island Passage or from Mindoro Strait via the Tablas Strait, that water is too fresh. The source must be San Bernardino Strait; derived from the upper 100 m of western Pacific stratification. There, as with Surigao Strait, surface layer water from the western Pacific can enter into the interior seas of the

Philippines [the Surigao may allow for only the upper 50 m of Pacific water to enter the Bohol Sea]. Consistent with this inference is that the s-max signature is stronger in the eastern Sibuyan Sea. In the Sibuyan Sea basin south of Sibuyan Island the subsurface s-max is absent, indicating that the San Bernardino inflow tracks to the north of Sibuyan Island. The San Bernardino s-max is observed in weaken form in Tablas Strait and in Maniquin Sea and along the eastern side of Mindoro north. The EAS16th model shows something like this at the 100 m level. The early June data in Maniquin Sea does not show the San Bernardino s-max, but it is evident in late June- another indication of the evolving summer monsoon effect?

• The formation of an s-max near 100 m indicates that San Bernardino allows for a thicker layer of western Pacific surface water to flow westward, than observed via Surigao Strait, which allows only the upper 50 m of Pacific water to enter into the interior Bohol Sea. It is possible that the difference is not just a sill depth issue as the western Pacific baroclinic geostrophic boundary condition differences at 13°N versus 10°N may be a factor.

• Deep Basin ventilation. There are two basins within the Sibuyan Sea: one north, one south of Sibuyan Island; Tablas Strait is west of Tablas Island. The deep isolated basins of the Sibuyan Sea are ventilated via the Tablas Strait [though we observed no active spill-over benthic layer structures]. Tablas Strait has a bottom potential temperature of 9.75°C. the basin north of Sibuyan Island at a bottom θ of 10.45°C. has a controlling sill of 460 m [thermometric sill depths, which is likely shallower than the actual deepest connecting depth to the west]; and the basin south of the Sibuyan Island at bottom θ of 10.70°C, has a sill of 420 m. Current below 400 m is generally less than 5 cm/sec. In the confines of the deep basins the oxygen concentration drops off without a change in T/S. This indicates oxygen loss of oxidation. In the northern basin the oxygen is 1.5 ml/l near 800 m [perhaps the recent depth of overflow ventilation], dropping off within the isothermal profile to 0.7 ml/l at the basin floor. In the southern basin the oxygen is quite a bit lower, as it is more removed from the open ocean oxygen source. At 600 m the oxygen is 0.5 ml/l, at the floor of the southern basin, ~1320 m, the oxygen drops to 0.3 ml/l, without change of potential temperature. *Speculation*: the basins are ventilated more effectively during El Niño when the regional stratification shallows. Might it be that the deep basin oxygen reduction, 0.8 ml/l in the northern basin, 0.2 ml/l in the southern basin been developed since the 1997 El Niño, 0.08 ml/l-yr, and 0.03 ml/l-yr, respectively? Of course, the actual consumption rate depends not just on ocean ventilation, but also supply of organics.

[G] Summary Schematics:

Figure 10 presents a schematic based on the PhilEx Exploratory Cruise of the mean [non-tidal] circulation pattern along a ~zonal plane for the region from the Dipolog Strait, across the Bohol Sea and through the Surigao Strait, into the Leyte Gulf, and western Pacific. A salinity section is inserted to provide some context, but the full T/S/Oxy stratification as well as the LADCP and hull ADCP info were brought into the schematic construction. Schematics are meant to faithfully syntheses a wide range of data into a coherent picture. I think I got it right, but please consider this to be a 1st draft. The 0.4 Sv value is what I think closer to the upper limit of surface water transport out of the Surigao Strait into the Bohol Sea, it is a blend of Pacific and Bohol water that entered into the surface stream be entrainment from below.

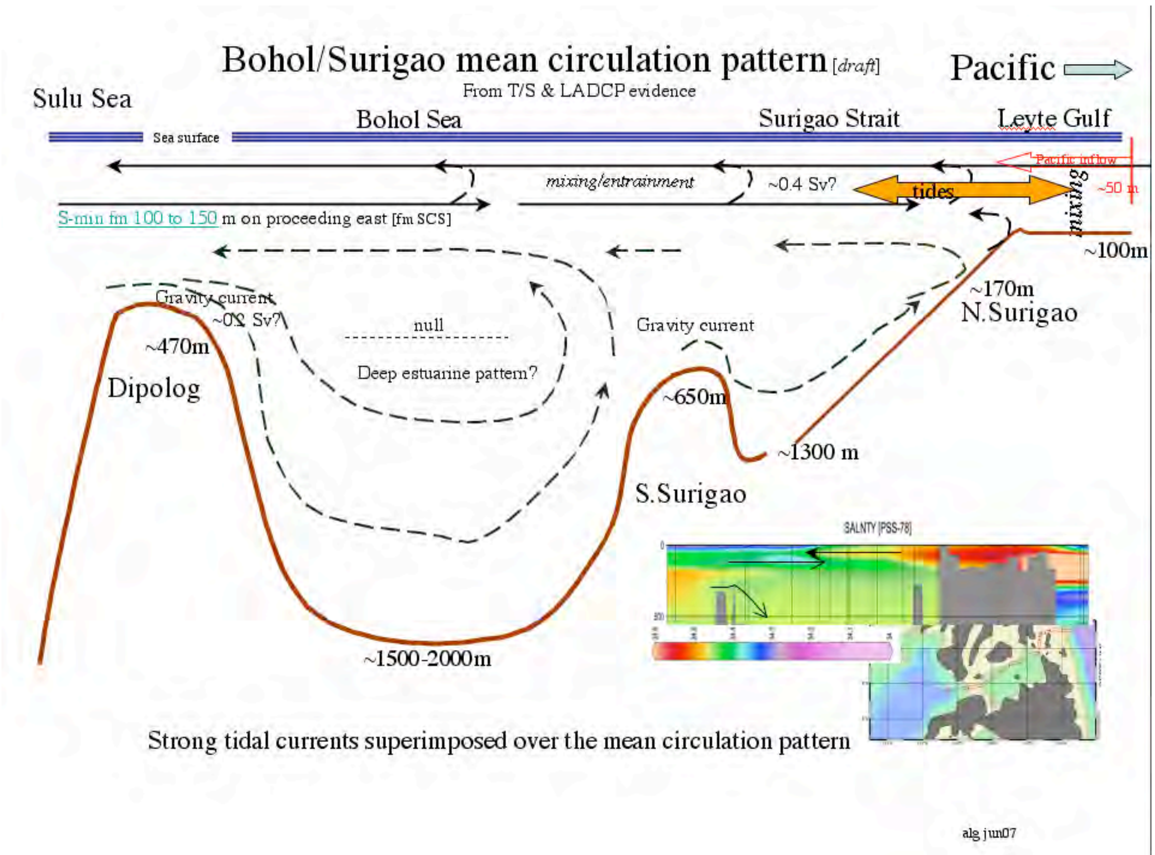


Figure 10 Bohol/Surigao mean circulation pattern built upon T/S & hull-L-ADCP evidence.

• Mindoro Schematic [Figure 11]: As a representation of the integrated data set of the Exploratory Cruise a schematic of the Mindoro Strait oceanography is presented.

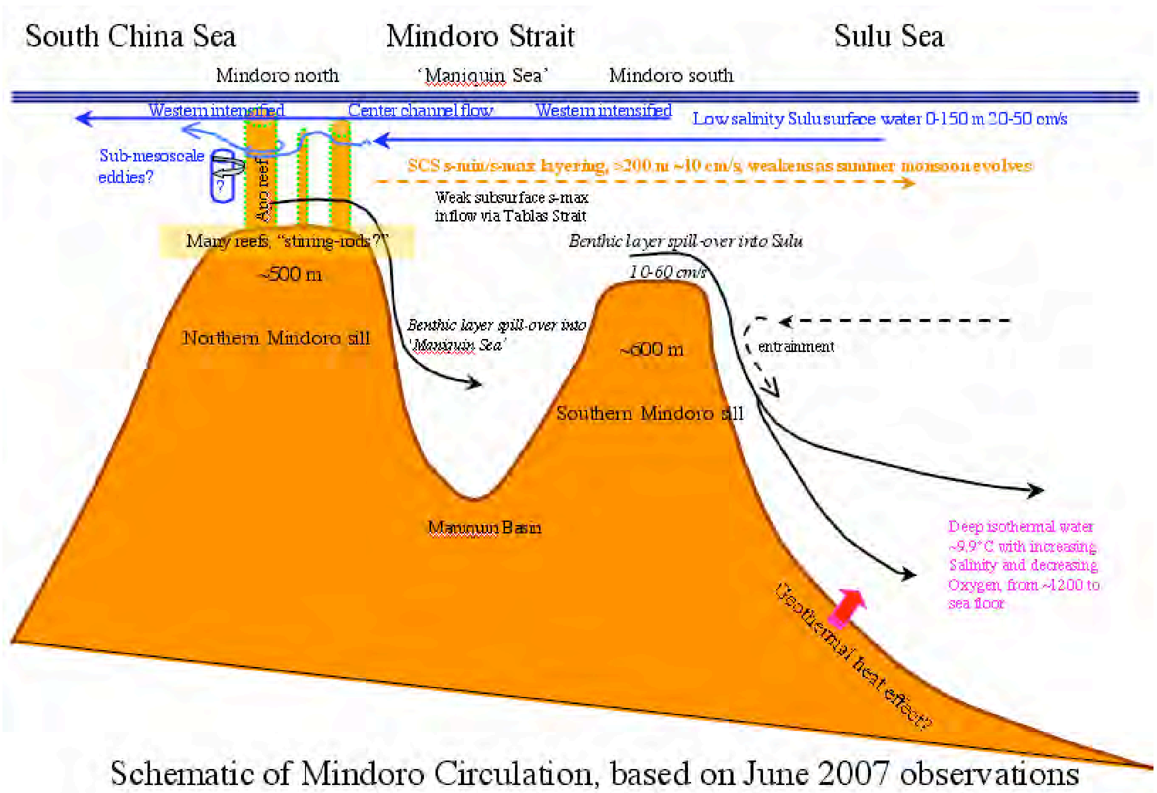


Figure 11. Mindoro Strait Schematic of along axis circulation and stratification; and of summer monsoon circulation pattern. Mindoro-north along-channel flow initially at the eastern/central channel, but shifts to west by Apo Reef

VI Comments/Suggestions:

The exploratory cruise provides much data to enhance our understanding and insight of the oceanography of Philippine waters, as required for planning of the IOP activities in January-March 2008 and January-March 2009. A brief list of factors to consider in the planning of the IOP are given below:

§ Western Pacific water of the upper ~100 m via San Bernandino Strait and ~50 m in Surigao spread into the adjacent Philippine seas with some influence on the Mindoro stratification (and circulation?), though the dominant forcing within Mindoro Strait has to do with South China Sea and the Sulu Sea interaction via Mindoro north and south segments, with some contribution from the Tablas Strait, which together representing complicated trio of straits joined at the Maniquin Sea.

§ Estuarine type circulation is characteristic of the upper 300 m Bohol Sea, the Pacific surface flow being the "river", the Sulu Sea being the "coastal ocean".

§ Overflow of relatively dense water into the confines of the Sulu Sea, Bohol Sea, Maniquin Sea and Sibuyan Sea are energetic features of the circulation and shape the stratification below associated sill depths. The deep isolated Sulu Sea may experience effects of geothermal heating, and perhaps ventilation timing linked to El Niño episodes.

§ Tides are very much in evidence in the circulation and overflow throughout the Philippine waters, but they are really strong in the Surigao Strait region, shaping the estuarine circulation pattern of Bohol Sea, and the spreading of the Pacific inflow.

§ The numerous reefs in Mindoro north may act as "stirring rods" creating a field of eddies and wake phenomena within the mean flow, and as such may deserve attention during the Mindoro IOP.

§ The Mindoro circulation in late June differed from that of early June, which may mark the maturing of the summer monsoon regional forcing.

§ During the Exploratory cruise we experienced very low wind and waves, generally ~10 kts though winds of slightly over 20 kts were more common in the northern Mindoro Strait at the end of June. Thus we observed ocean processes under minimal local wind action, exposing ocean processes driven by tides and remote forcing from the surrounding large water bodies. The winter season timing of the IOP will see much larger wind stress curl conditions.

• Small fishing boats and poorly marked fish aggregators abound in the Philippine waters. This will force some deviations of well planned observations along repeat and towed vehicle operations during the IOP. Additionally, permission to work within 15 km of the coasts of many regions is required.

VII Acknowledgements:

Living up to the name "Exploratory Cruise", we explored the regional and strait oceanography. This meant that while we had a conceptual strategy, the details of our day-to-day observational activities depended to a large extent on those of the previous day or two. We had to respond fairly quickly to what the data suggested, so as not to miss opportunity. This made for a very intense cruise. The team of researchers and support staff and ship officers and crew displayed remarkable level of teamwork in a most congenial manner. Everyone aboard is a true professional.

The Philippine researchers, particularly their leaders, Cesar Villanoy and Laura David, are to be especially commended. Their cheerful attitude, their ability to anticipate, their sense of responsibility to their watches are truly admirable.

I must say I never had a more agreeable group of official Observers on my previous cruises. They pitched right into the work, becoming integral members of the team. Very impressive. Fernando "Ding" Magno played an essential role in communicating with fishing fleets that we encountered, including returning of 'rescued' microstar drifters.

The US researchers displayed a positive sense of sharing information and expertise. The Scripps techs, Robert Palomares and Drew Cole are just excellent, always there when needed.

The many graduate students on the research staff will all make in their time wonderful oceanographers.

My thanks to Captain Christopher 'Rip' Curl and the mates for safe passage through all of the hazards of archipelago waters, with its many small fishing boats and nets and the poorly marked fish aggregators; and to the Engineers who kept the ship cool and comfortable in the tropical clime.

VIII Science Personnel list

Last, First Name	Institution	
1. Gordon, Arnold	Lamont-Doherty Earth Observatory	Chief Scientist
2. Huber, Bruce	Lamont-Doherty Earth Observatory	Scientist
3. Mele, Philip	Lamont-Doherty Earth Observatory	Scientist
4. Giulivi, Claudia	Lamont-Doherty Earth Observatory	Scientist
5. Tessler, Zachary	Lamont-Doherty Earth Observatory	Graduate Student
6. Tillinger, Debra	Lamont-Doherty Earth Observatory	Graduate Student
7. Pujiana, Kandaga	Lamont-Doherty Earth Observatory	Graduate Student
8. Ohlmann, Carter	University of California Santa Barbara	Scientist
9. Sybrandy, Andrew	Pacific Gyre	Scientist
10. Engel, Patricia	MIT/Woods Hole Oceanographic Inst.	Graduate Student
11. Villanoy, Cesar	University of the Philippines	Scientist
12. David, Laura	University of the Philippines	Scientist
13. Cabrera, Olivia	University of the Philippines	Scientist
14. Alabia, Irene	University of the Philippines	Scientist
15. Floren, Adonis	Silliman University	Scientist
16. Palermo, Joseph	University of the Philippines	Scientist
17. Martin, Joseph	University of Washington	Scientist
18. Galang, Juanito	Philippine Atmospheric Geophysical and Astronomical Services Administration, Observer	
19. San Joaquin, Arnold	Philippine Navy	Observer
20. Magno, Fernando	Philippine Coast Guard	Observer

Huber and Cabrera left the ship in Cebu;

Ohlmann and Sybrandy joined the ship in Cebu.

Appendices [figure numbers referred to in each appendix are the figures incorporated into each appendix, not those of the main text]:

[A] Cesar Villanoy and Laura David: Bio-optical.
[B] Carter Ohlmann: SVP and microstar drifters

APPENDIX A

Bio-optical Measurements

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Bio-optics measurements made during the cruise include the transmissometer, fluorometer and CDOM Fluorometer deployed with the CTD rosette. The ship's underway system also measures fluorescence and other parameters and logged every 30 secs. Details about the instrument specs are shown in Table 1 and 2. The CTD fluorometer did not work properly during the first nine casts but worked reasonably well for the rest of the CTD casts. Phytoplankton samples were also collected by filtering through a 20μm sieve water collected from 10m and from the depth of the deep chlorophyll maximum (DCM). Samples were preserved with formalin.

• Underway system

A summary of the data collected using the underway system is shown in Figure 1. Surface salinity values are higher in the eastern Bohol Sea showing the entry of Pacific surface water through the Surigao Strait. The eastern part of the Sibuyan Sea also shows higher salinity compared to areas in the west. Again, this may also be Pacific surface water but entering the internal seas via the San Bernardino Strait.

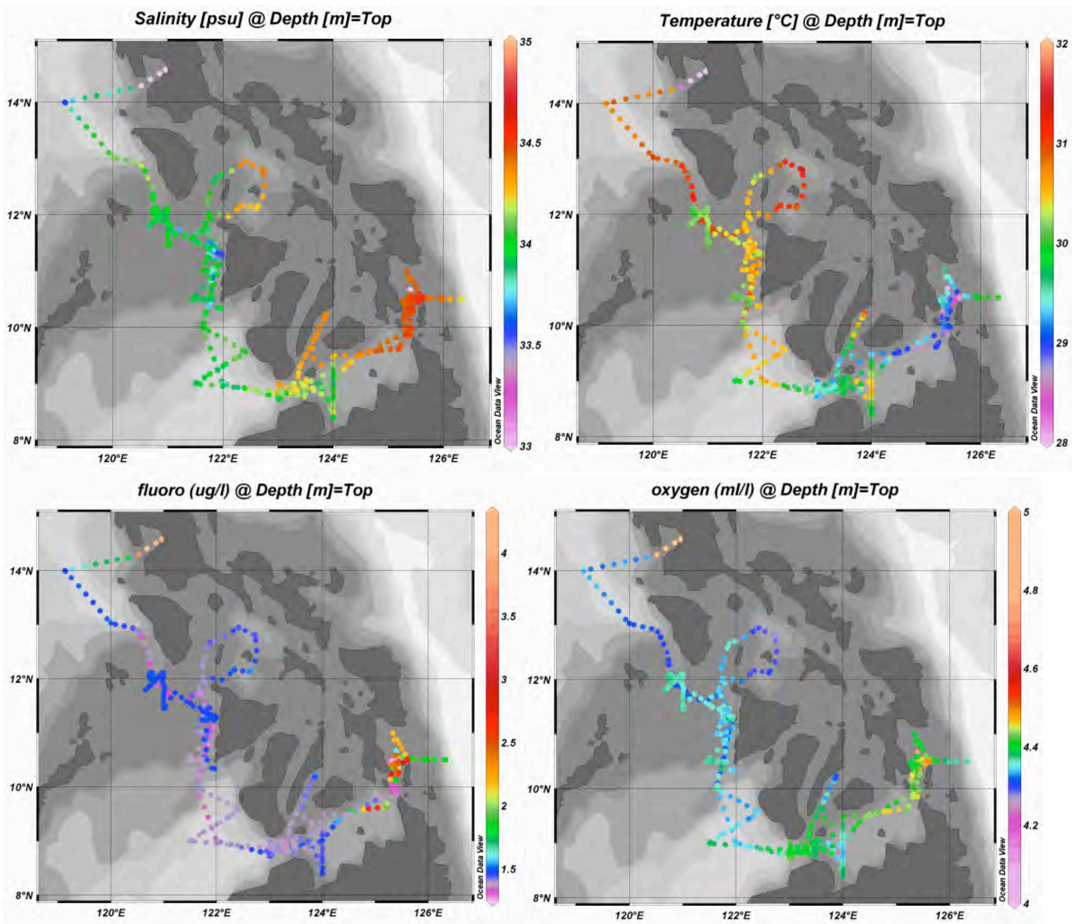

Figure 1. Hourly average values of underway parameters

Sea surface temperature and dissolved oxygen concentrations show distinct differences between basins with cooler temperatures and higher dissolved oxygen concentrations at the surface in the Bohol Sea compared to the Sulu Sea. These two parameters show strong diurnal variations and therefore may also reflect both temporal and spatial variations. Underway fluorometer readings show the highest chlorophyll concentrations in Surigao Strait and relatively higher concentrations within straits, most likely due to more vertical mixing as will be seen in chlorophyll profiles from the CTD casts.

• Bio-optical measurements from CTD casts.

The CTD was deployed to profile up to the bottom except for a few stations in the Sulu Sea and the South China Sea. The location of the CTD casts are shown in Figure 2. No fluorometer readings were obtained at Stations 1-9 because of a defective sensor. All the fluorometer and transmissometer profiles are shown in

Figure 3. The chlorophyll concentrations are low at the surface, increasing to a maximum at the deep chlorophyll maximum (DCM) and decreasing with depth until 200m. The color of the dots represent raw voltage values of transmissivity. Higher values represent

higher light transmissivity. Note that at the DCM, transmissivity is lower indicating that plankton is the main scatterer of light at those depths.

Factors which can influence the depth of the DCM as well as the chlorophyll concentrations include water column stability and mixing, light extinction, and nutrient availability. Figure 4 shows the chlorophyll profiles for each of the basins and the straits connecting them. The DCM is deepest (>100m) out in the Pacific east of Surigao. Within Surigao Strait, the DCM is significantly shallower (<100m) with some stations exhibiting no DCM at all. The maximum concentration in Surigao Strait is similar to the maximum in the Pacific. The chlorophyll profiles in Bohol and Dipolog Strait show a well defined but shallow DCM (50-60m). The difference is that concentration at the DCM is higher in Dipolog Strait compared to Bohol Sea. The Sulu and Mindoro Strait profiles also show a similar characteristic. Generally straits have higher concentrations at the DCM and may be a consequence of more intense vertical mixing because of stronger currents and current shears.

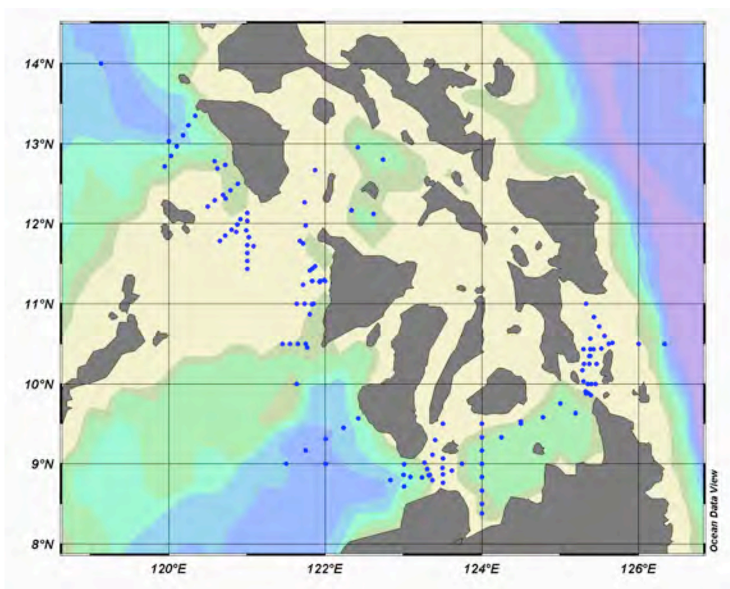

Figure 2. CTD stations with fluorometer and transmissometer readings.

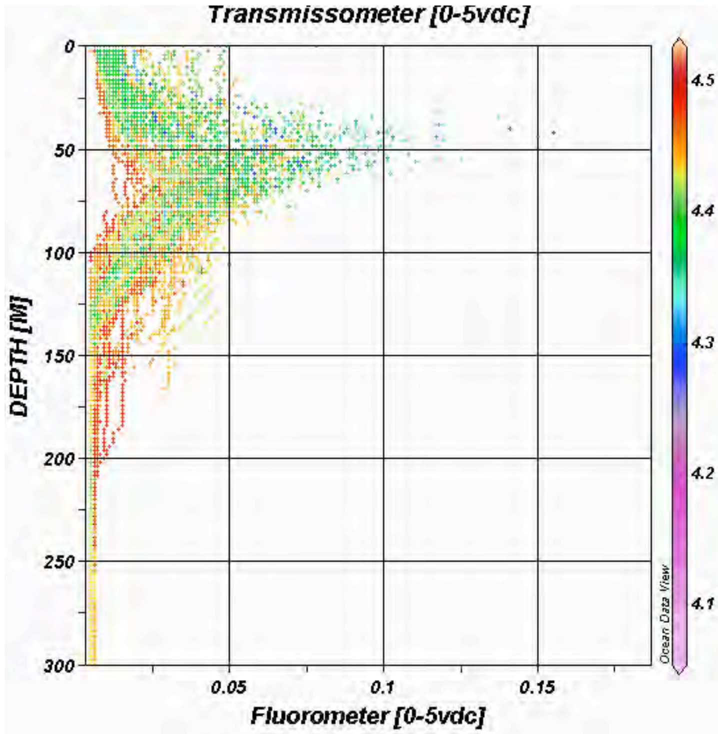

Figure 3. Scatter plot of all fluorometer & transmissometer measurements. Values are in raw voltages.

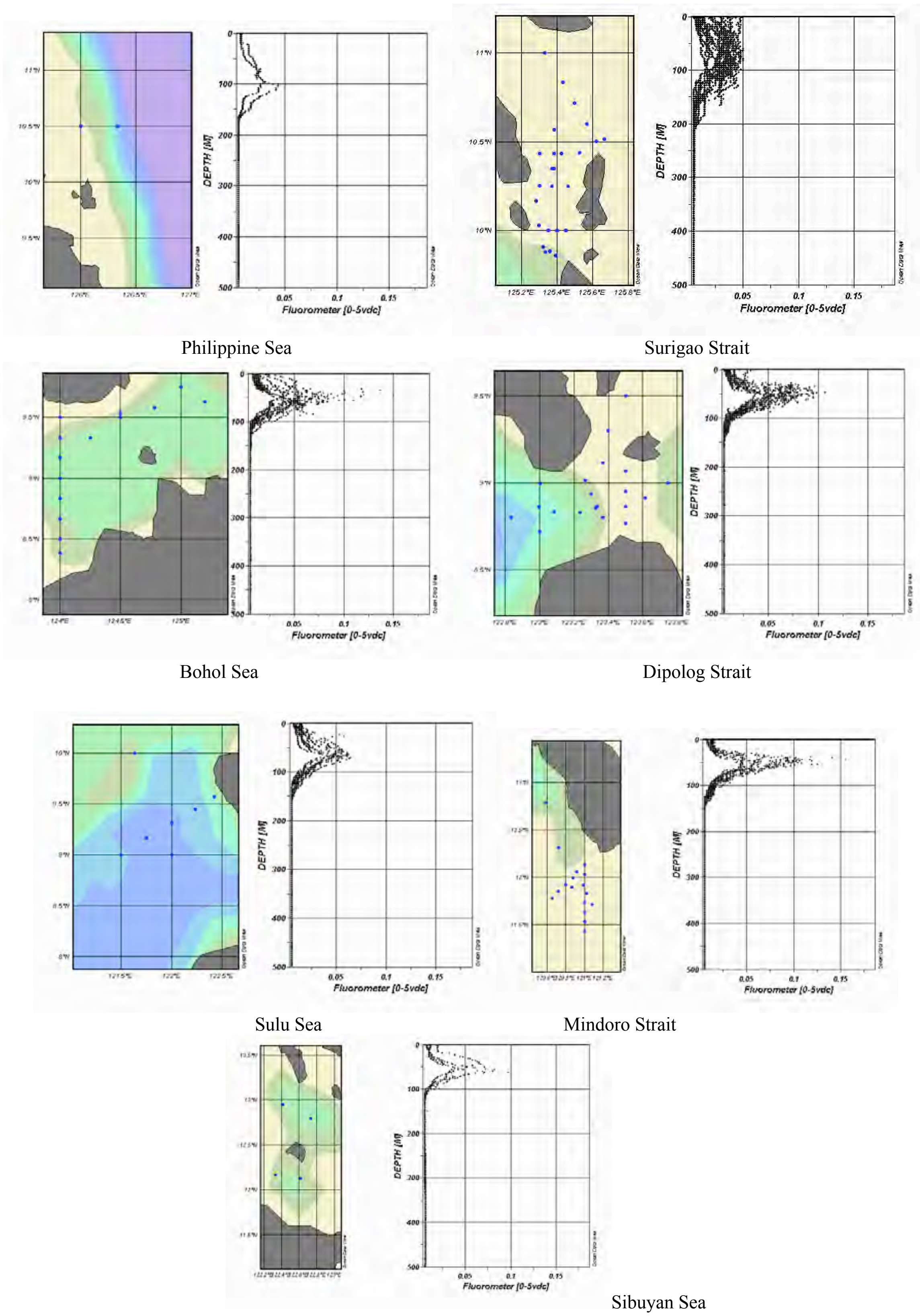

Figure 4. Fluorometer profiles for different areas in Bohol and Sulu Seas.

§ Analysis of underway chlorophyll along 124°E section across Bohol Sea eddy

Correlation between surface chlorophyll with other parameters was attempted only for the meridional section along 124°E in the Bohol Sea. Hull and lowered ADCP data suggests the presence of an eddy across this section. Meridional surface chlorophyll values derived from underway data shows defined sections of chlorophyll concentration varying with Sea Surface Temperature (SST) along 124°E and 8.4-9.5°N (Figure 5). The sections include areas of low temperature and low chlorophyll (pink box), high temperature and high chlorophyll (red box), and low temperature and high chlorophyll (blue box). Scatter plot of temperature against fluorometer data further highlights the temperature-chlorophyll correlations in the previously observed portions of the transect (Figure 6). The region characterized by high temperature and elevated chlorophyll appeared to be at the core of the cyclonic eddy. However, the observation was inconsistent with the surface temperature signal for counterclockwise gyre circulation. Atmospheric forcing and local heating possibly account for the warmer surface temperature at the eddy's core. The scatter plot of temperature versus long wave radiation appears to show a positive correlation (Figure 7), possibly underscoring the influence of local heating in warming surface waters. Further dissection of vertical temperature profiles from CTD data along the region shows the uplift of cold subsurface water at depths around 50m (Figure 8). However, it can be noted the sea surface temperature is also warmest where the isotherms are doming. Although surface temperatures are high, possible nutrient transport associated with the isotherm doming may increase primary productivity resulting in a relatively higher chlorophyll concentration at the surface.

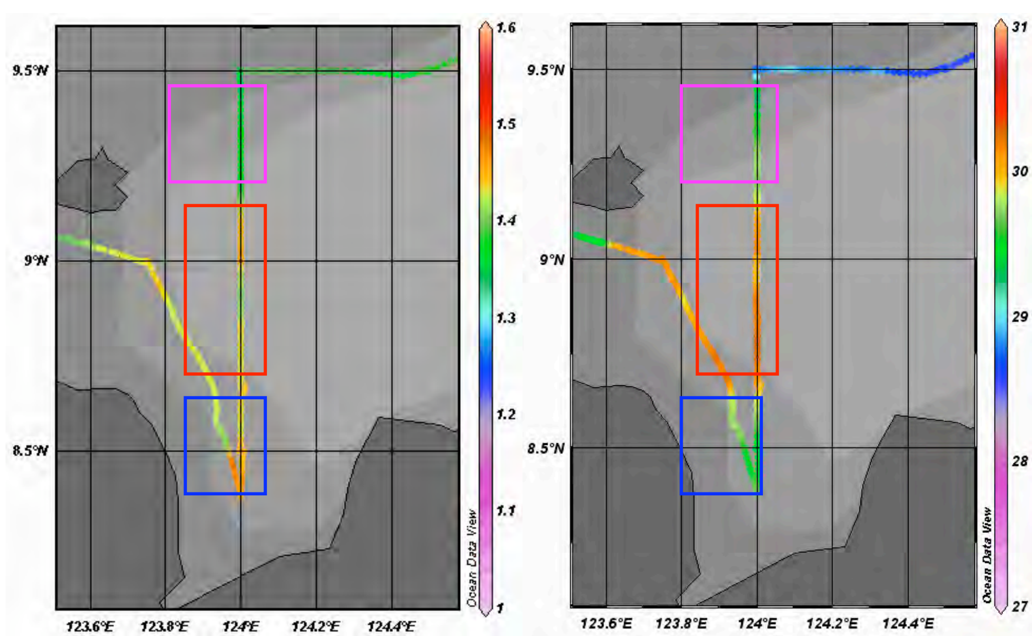

Figure 5. Underway chlorophyll concentration (left) and SST (right) along meridional track at 124ºE in the Bohol Sea.

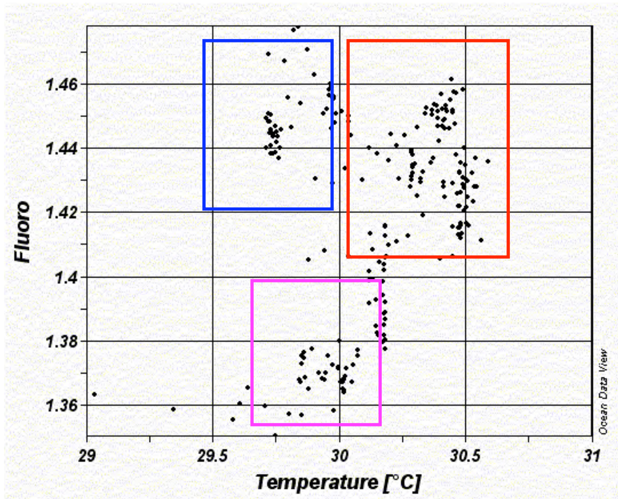

Figure 6. Scatter plot of fluorometer with sea surface temperature from the underway data.

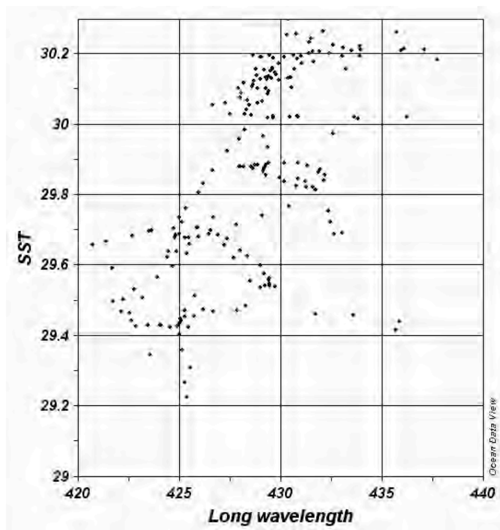

Figure 7. Scatter plot between sea surface temperature and long wavelength radiation.

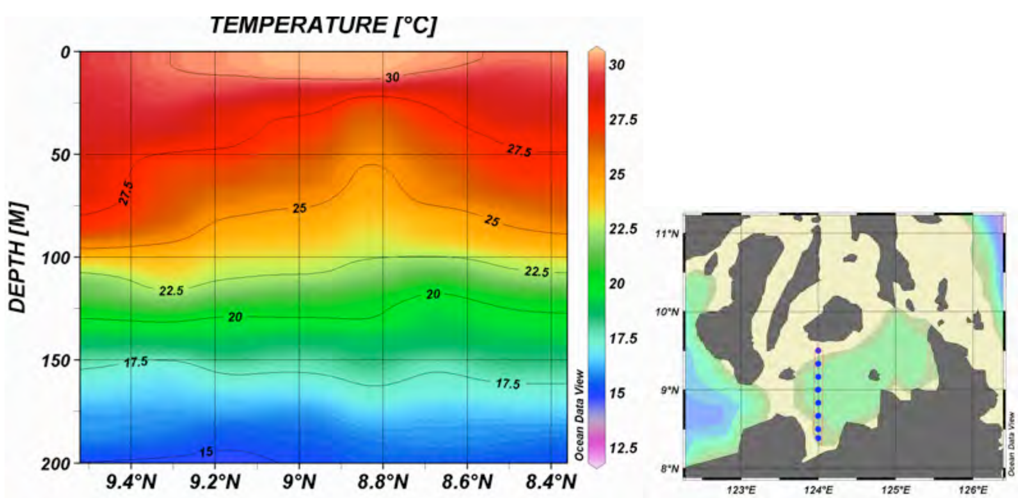

Figure 8. Meridional temperature section across 124°E

APPENDIX B
PhilEx Exploratory Cruise Drifter Data

Carter Ohlmann
R/V Melville
PhilEx Exploratory Cruise
3 July 2007

1. Goal

The primary goal of PhilEx Exploratory Cruise is to "provide information on the regional and strait sub-regional circulation to enhance design of the '08 and '09 IOP's". Towards this end, a set of **drifting buoy deployments** were performed to observe the surface circulation over a wide range of scales. The drifters measure "surface" currents at depths shallower than resolved with cruise ADCP data, they sample on higher frequencies than with averaged ADCP data, and record data in locations beyond the cruise track. In addition, they measure velocities in a Lagrangian framework. These drifter experiments are described here.

2. Instrumentation

Two types of drifting buoys were utilized, Surface Velocity Program (SVP) drifters for sampling the regional circulation or the large scale, and Microstar drifters for the strait sub-regional, or small scale.

SVP drifters are comprised of a holey sock drogue roughly 0.6 m in diameter and 6 meters in length, and centered at a depth of 15 m. The drogue is attached to an ABS plastic surface float with a diameter of near 0.4 m that houses electronics. SVP drifters obtain their position every 1 hour with GPS, and by Doppler ranging with the Argos system whenever an Argos satellite is in view (pass intervals variable between ~30 minutes and 4 hours). Data, including position and SST, are transmitted via Service Argos and available from a host computer roughly 2-3 hours after collection.

The SVP drifters are similar in style to the roughly 1250 units presently sampling the world ocean as part of the Global Drifter Program, with the addition of hourly GPS position data necessary to properly resolve semi-diurnal tides. The half-life of SVP drifters with hourly GPS data is roughly 1 year, making them an adequate tool for sampling the regional circulation. The utility of the SVP drifters for this project is in sampling the regional scale circulation of the Sulu Sea and determining the fate of water parcels entering the South China Sea, where drifters must sample for long periods. For the strait sub-regional circulation, where water parcels enter and exit in a few days or less, the sampling times (both frequency and life) are too long.

Microstar Drifters use a corner-radar-reflector type drogue roughly 1 m in diameter centered at a depth 1 meter below the sea surface. Electronics are housed in an ABS plastic surface float roughly 20 cm in diameter. Microstar drifters obtain their position every 10 minutes with GPS and transmit their data every 30 minutes through the Iridium communications system. Data are received aboard the R/V Melville while at sea using a portable Iridium modem, or base station. The availability of near real-time data (every 30 minutes) allows the drifters to be recovered and redeployed. Using the drifters in a catch-and-release manner greatly improves the economy of drifter experiments as a single instrument can be repetitively placed within a region/feature. The half-life of Microstar drifters is roughly 8 days, constrained by float size (i.e. batteries) and sampling frequency. The utility of the Microstars for PhilEx is in repetitive sampling of fine scale (hours-days, 0.1 – 10's km)) sub-regional circulation.

2. Deployments

A set of 6 drifter deployments were performed during the PhilEx Exploratory cruise. Each deployment was characterized by the release of between 2 and 12 drifters within a specified region. Track lengths ranged from 5 hours to 4 days for the Microstar drifters. SVP drifters sampled during the last 2 to 14 days of the cruise and are expected to continue their measurements over the coming months.

The deployments marked a number of "firsts" that include: the first data collected from substantial numbers of drifters deployed together within the Philippines Archipelago (a few mostly individual tracks have been collected over the years); the first time that large numbers of drifters using Iridium communications have been used in a scientific experiment; and the first time sets of more than a few buoys have been deployed, retrieved, and redeployed from a large research vessel with efficiency and ease. The key to the novelty of the measurements lies in the Iridium SBD communications system which allows high frequency data to be obtained economically in near real-time aboard a research vessel.

Dipolog Strait – Sulu Sea SVP deployment

A set of 8 SVP drifters were deployed in the region of the Dipolog Strait. Exact deployment locations were selected to be along the ship's CTD/ADCP sampling track where drifters would hopefully be advected westward and into a presumed large scale gyre in the north-east Sulu Sea. SVP sampling details are given in Table 1 and tracks through the end of the cruise (writing of this report) are illustrated in Figure 1.

Drifters deployed in the Dipolog Strait (#'s 28, 32, and 33) show west-southwest movement into the Sulu at a mean velocity near 0.25 m s^{-1}. Drifter #28 did not successfully transmit GPS data, so Argos position data is shown. Drifter # 32 was picked up by a local boat and taken to Negros 1 day after deployment. Drifter #33 has successfully transmitted both GPS and Argos position data during the course of its mission and continues to do so. Drifters deployed to the west and northwest of the Dipolog Strait show southerly and western movement. The two drifters that move mostly west do so at only ~0.05 m s^{-1}, a velocity that has remained consistently low during the course of deployment. The two drifters deployed nearest shore (Negros) show southward movement at ~0.10 – 0.20 m s^{-1} and were entrained in the westward moving Dipolog outflow and into the Sulu Sea.

Drifter ID	deploy location	deploy time (UTC)	# days sampled	termination/comments
75428	Dipolog 8 59.250 123 17.268	20.6.07 0804	14*	
75429	Mindoro/SCS	2.7.07 0958	2*	
75430	Dipolog/Sulu 8 57.417 121 59.725	21.6.07 0931	1	unknown
75431	Mindoro/SCS	2.7.07 0728	2*	
75432	Dipolog 8 56.184 123 17.814	19.6.07 2155	1	picked up by boater
75433	Dipolog 8 55.320 123 18.650	20.6.07 0737	14*	only Argos positions after 7 days
75434	Dipolog/Sulu 9 18.409 122 00.266	22.6.07 0058	14*	
75435	Dipolog/Sulu 9 09.489 121 44.852	21.6.07 2025	14*	
75436	Dipolog/Sulu 9 00.853 121 31.316	21.6.07 1528	3	picked up by boater
75437	Dipolog/Sulu 10 00.757 121 28.256	22.6.07 1510	14*	

Table 1. SVP drifter deployments during PhilEx Exploratory cruise. Deployment time is given in UTC. * indicates drifter is still sampling at time of this writing (3 July ’07).

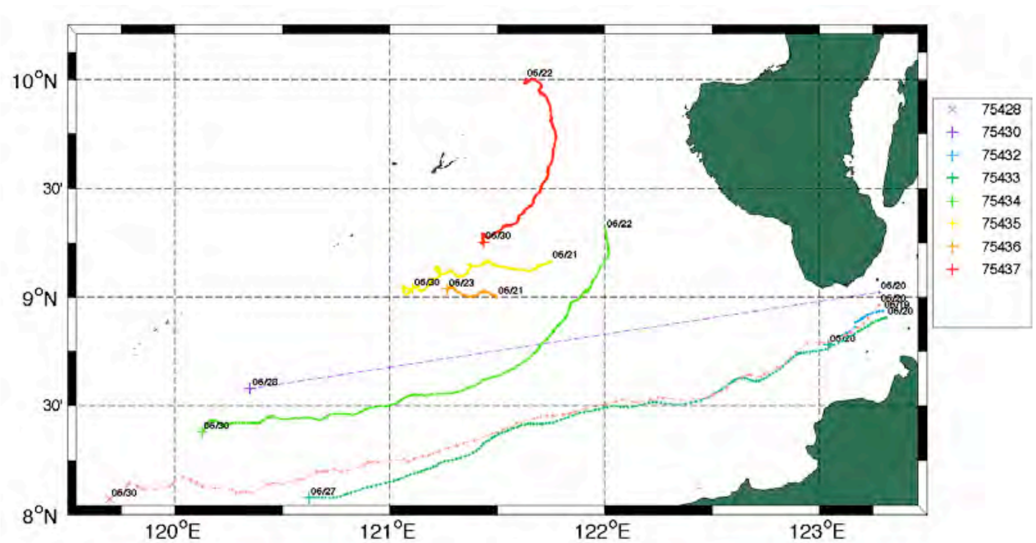

Figure 1. Tracks of SVP drifters deployed in the Dipolog – Sulu Sea region. Dates in mm/dd format show times at deployment and the most recent position available. Hourly GPS position indicated by each dot is shown when available. Dashed lines for drifter #’s

75428 and 75430 are from Argos positions acquired by Doppler ranging as GPS positions did not report. Drifter # 75430 traveled 8 days between successive position records.

The drifter data support the idea put forth by Chief Scientist Gordon (based on ADCP surveys) that an anti-cyclonic eddy exists off the west coast of Negros. CTD data show water properties confined to the eddy with surface water from Dipolog flowing northward to Mindoro along the western edge of the eddy. Drifter numbers 35 and 36 show extremely small velocities for an extended period of time suggesting they might be trapped within the central region of such an eddy, and confirming the possibility of confined waters. Drifter number 34 and 37 suggest return flow along the inshore edge of an eddy. A diurnal signal (presumed tidal) is clearly evident in many of the drifter tracks either through abrupt changes in direction (drifter #35) or changes in velocity along a track with a mostly constant direction (drifter #33).

Mindoro Strait – South China Sea SVP deployment

A pair of SVP drifters were deployed in the extreme northwestern region of the Mindoro strait where it meets the South China Sea on the last sampling day of the cruise. The deployment location was near the center of the strait where the hull ADCP and Microstar drifters show northwestward flow near 0.70 m s^{-1}. Deployment was within a few kilometers of the location of Microstar drifters that moved from the Mindoro/Tablas region to continue the tracing of surface waters that originated within the central archipelago.

Mindoro Strait – South Sill Microstar Deployment #1

A set of 10 Microstar drifters were deployed in an embedded grid structure ~5 km south of the South Sill Mooring (11 16.651 N, 121 55.444). Embedded grids with 100 m, 400 m and 900 m spacing were chosen to observe the very fine scale structure of the surface flow moving through the strait (Figure 2b). The deployment location was selected, based on ship ADCP data, so the drifters would arrive at the mooring latitude roughly 8 hours after deployment for convenient recovery. A primary goal of the deployment was to determine the length of time for drifter recovery, as this was the first occurrence of real-time GPS drifters being recovered en-masse from a large research vessel. To the surprise of many, recoveries from the R/V Melville were both quick and smooth, albeit in extremely calm (wind/wave) conditions. Drifters were deployed on 25.6.07 between 0215 and 0310 UTC and recovered roughly 5 hours later. Recovery time from sighting the first drifter to bringing the final (10^{th}) on board was 95 minutes.

Drifter velocities began northward at ~0.20 m s^{-1}, less than given by the top bin of the hull ADCP (~20 m), and decreased by ~50% during the short deployment. The eastward velocity component increased from near 0 to ~ 0.10 m s^{-1}. An obvious feature of the small scale flow evident from the raw data is negative vorticity, with both $\partial v/\partial x$ and $-\partial u/\partial y < 0$ (quadrilateral in Figure 3). The stronger northward flow in the western strait is consistent with western intensification of boundary currents.

An important result of the first Microstar drifter deployment is the ease with which drifters were recovered from the R/V Melville. Primarily considered expendable due to the delay in receiving data from the store-and-send Argos telemetry system, Iridium drifters are now clearly recoverable and reusable, even aboard large ships. This increases drifter economy and allows for robust flow statistics to be collected with a relatively

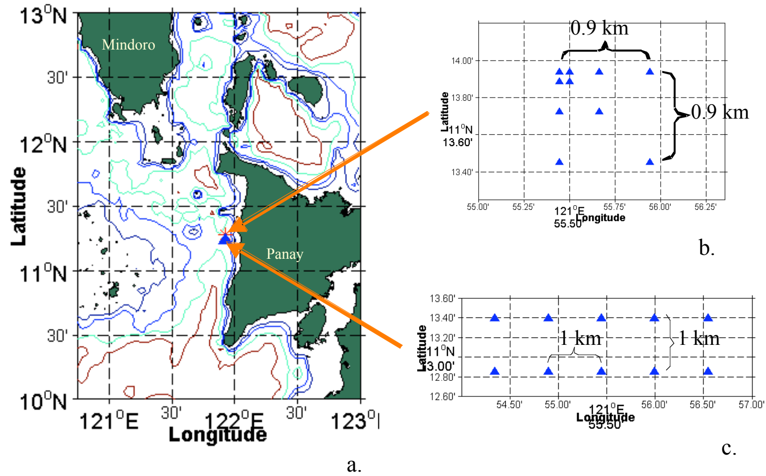

Figure 2. Drifter deployment locations for the a) small scale, and b) large scale Microstar experiments over the south sill of the Mindoro Strait.

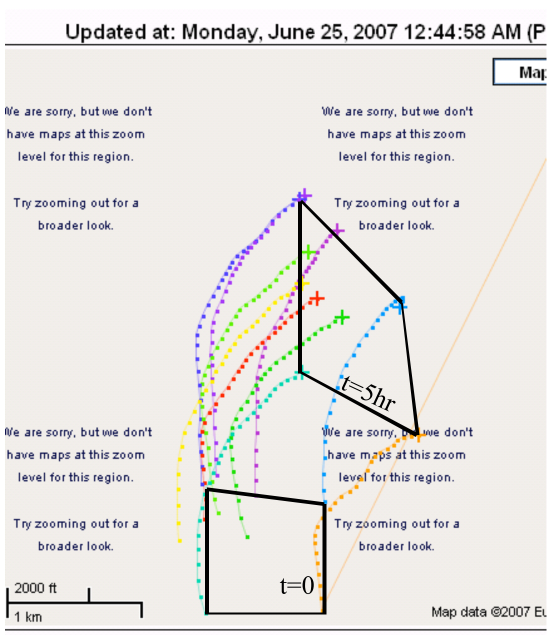

Figure 3. Screengrab of the drifter monitoring system at the end of the first Microstar deployment. Colored dots indicate drifter positions every 10 minutes; plus signs indicate

ending positions. Quadrilaterals connect drifters comprising the outermost (0.9 km) grid at deployment (time = 0) and recovery (time = 5 hours).

small drifter fleet in areas where the small scale flow structure is targeted for study. The quantity of Philippino fishing boats throughout the Strait at all times caused concern about drifters being retrieved undesirably and taken ashore. Although some loss of equipment occurred, the local fishermen seemed to heed writing on each drifter that reads "science experiment, please do not touch".

Mindoro Strait – South Sill Microstar Deployment #2

A set of 10 Microstar drifters were deployed in a 5 x 2 cross strait configuration with 1 km spacing at a location 6 km south of the South Sill Mooring (11 16.651 N, 121 55.444; Figure 2c). Drifters were deployed during the early afternoon (~0600 UTC) on 26.6.07, and recovered roughly 48 hours later. The deployment location was selected, based on ship ADCP data and velocities of previously deployed drifters, so the array would cross the mooring latitude (where the ship was sampling) roughly 18 hours after deployment. The deployment grid and sampling time were chosen to observe the cross strait shear on slightly larger scales than for the previous deployment, and over more than a complete diurnal tidal cycle.

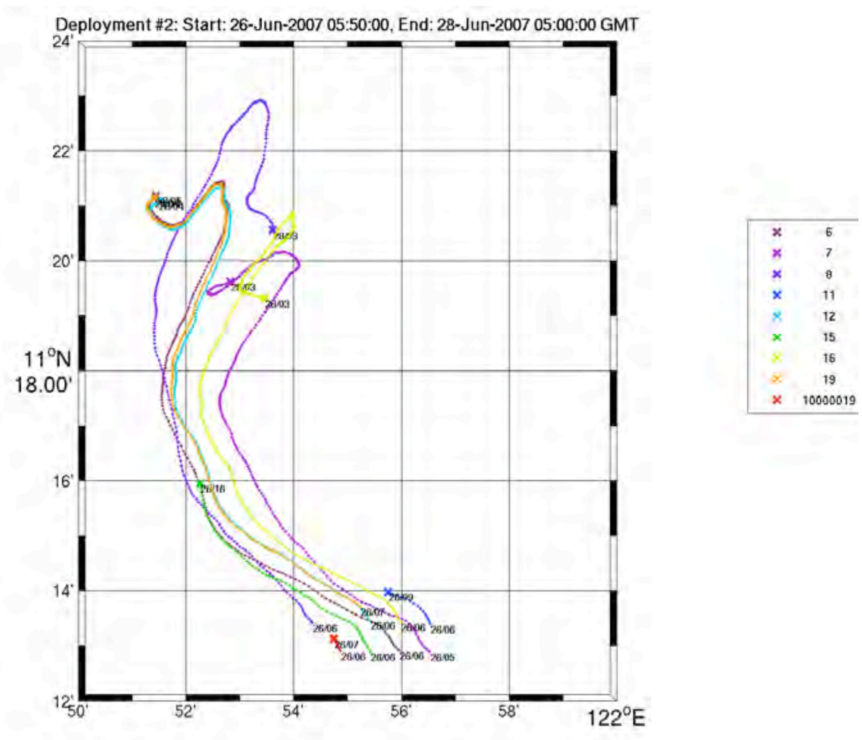

Figure 4. Drifter tracks during the second Microstar deployment near the south sill of the Mindoro strait. Dots indicate position recorded every 10 minutes. Tracks are color coded and x's denote ending positions. Track beginning and ending times are indicated in dd/hh format where dd denotes day of month and hh hour of day.

Drifters started out moving northeastward at ~0.25 m s^{-1}, turning to northwestward at reduced velocities, and eventually returned southward for a few hours (Figure 4). Velocity values computed as a first difference in position show appreciable variations on timescales which appear to be semi-diurnal and smaller. Velocity components appear both in phase and 180 degrees out of phase during the 48 hour sampling period. As for the previous Microstar deployment in the region, the drifter tracks generally illustrate anticyclonic vorticity, western velocity intensification, and significant variations on kilometer scales.

It was interesting that the regularly spaced array quickly rearranged itself into 4 separate patches. Upon retrieval, a set of 3 drifters (some of which were not communicating) was found within ~ 200 - 300 m, and a set of 4 drifters was found within another ~200 – 300 m region. At retrieval time drifters were located in regions of significant terrestrial flotsam (sticks, coconuts, etc.). Given the extremely light wind conditions, convergence patterns that act on scales of a few kilometers are hypothesized to be surface manifestations of internal motions.

One of the 10 drifters deployed was picked up by a fisherman and taken to shore. Considering that more than 50 small fishing boats were visible with the naked eye at one point, and numerous boats were the norm, this loss rate is not considered bad. Three drifters failed just after deployment due to what is believed to be an RF/ shielding problem with the instruments. Convergence patterns allowed 2 of the non-reporting drifters to be retrieved as they accumulated with working drifters whose position was known.

Mindoro Strait – Kambal Reef Microstar Deployment

A set of 12 drifters was deployed just downstream of Kambal reef, a small seamount located near the center of the channel southwest of the southern tip of Mindoro (12 03.30 N, 120 46.50 E). Arrays of drifters with 1 km spacing in 3 x 2 configurations were placed downstream of the seamount on both sides (Figure 5). The arrays were located on either end of the downstream section of the cruise track which was roughly 9 nm in length. The deployment scheme was defined to observe the influence of Kambal reef on the surface flow. The 1 km spacing was believed to be too fine to adequately observe the large scale flow around the reef given the number of drifter available. The spacing was chosen to be consistent with the past deployment so that variations in energy on km scales could be compared between regions.

Drifters all moved toward the northwest through the Mindoro strait with no evidence of a seamount reaching the thermocline, presumed to act as a stirring rod (Figure 6; there is slight turning of the drifter tracks well downstream of Kambal, but in the vicinity of a smaller seamount whose exact position needs to be further investigated). The western and eastern sets of drifters moved at ~0.50 and ~75 m s^{-1}, respectively, giving a horizontal shear over ~6 nm of ~$3x10^{-5}$ s^{-1}. The relative position of drifters within each grid remained relatively unchanged during the roughly 24 hour sampling period. Velocity variations of ~0.20 m s^{-1} occur over roughly a diurnal tidal cycle with little energy in shorter frequencies. North and east velocities are 180 degrees out of phase. Small

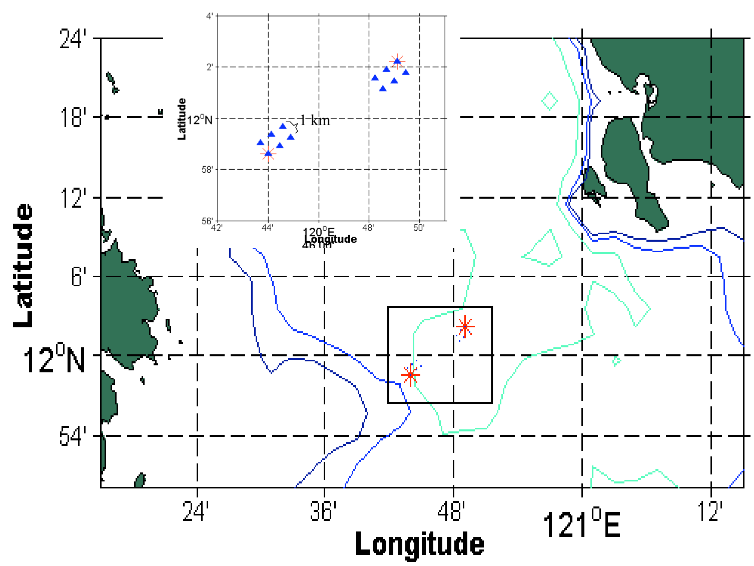

Figure 5. Deployment location near Kambal reef. Inset shows drifter spacing at location of red stars on large map.

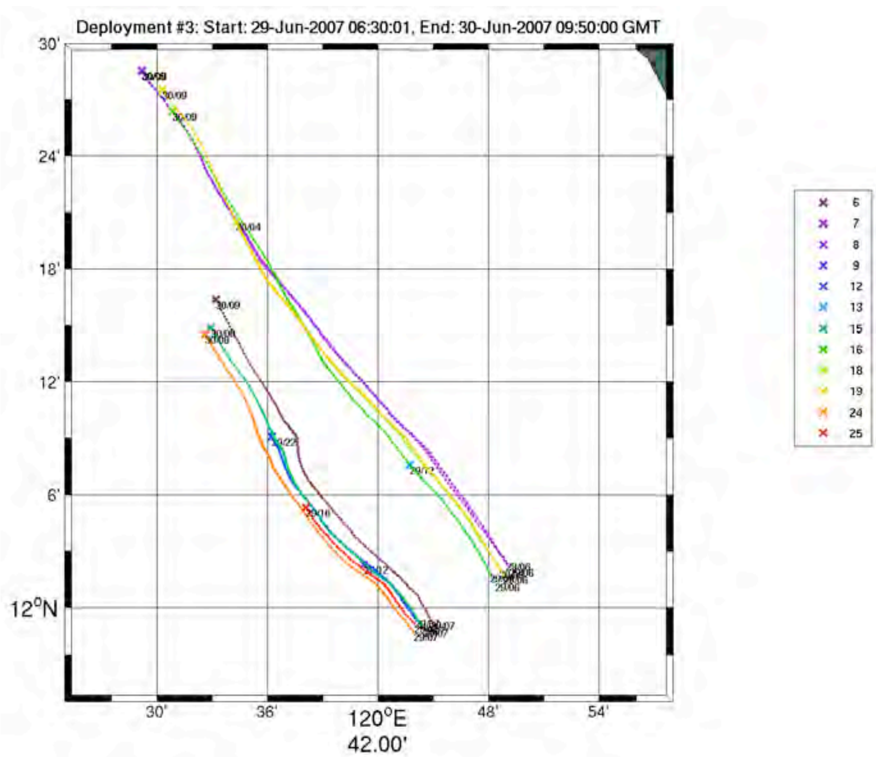

Figure 6. As in Figure 4 for drifters deployed downstream of Kambal reef.
northward velocities are accompanied by large eastward (small westward) velocities and visa versa.

Large scale energy for this deployment was significantly greater than for previous deployments. Small scale (1 km) energy appears less (this has not been calculated precisely). The flow is not westerly intensified as near the south sill. Vorticity due to significant shear over ~10 km is positive. Future deployments should investigate flow variations over 10 km scales in other regions. A more consistent grid of drifters (i.e. no big gap) should be used to look for an influence from the Kambal seamount. Two of the 6 drifters deployed in each group of stopped reporting position due to instrument error, 1 drifter was retrieved by a fishing boat in the region of Apo reef , a marine protected area with significant fishing activity at the boarder.

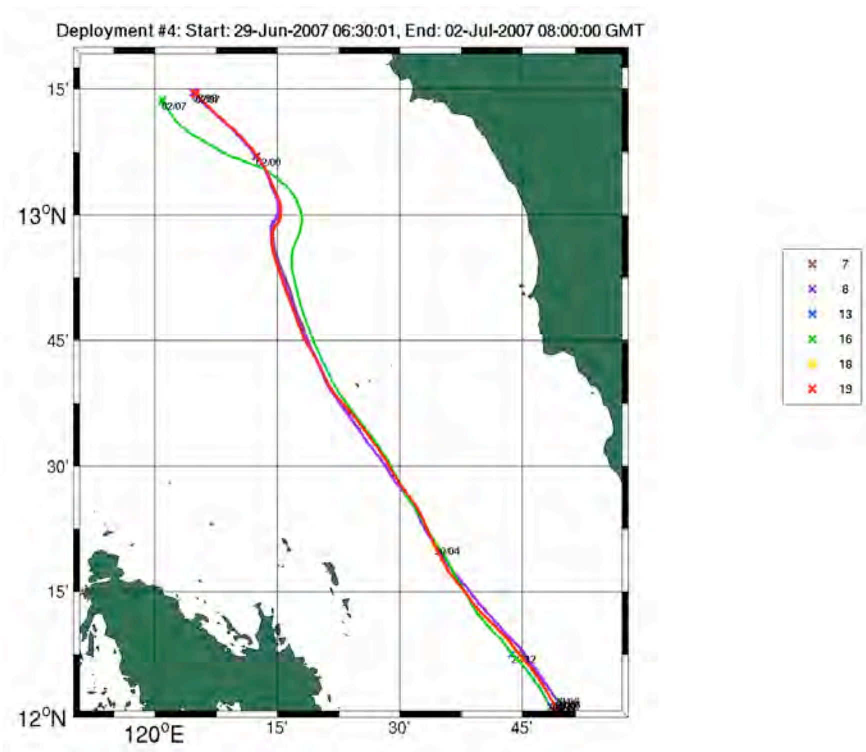

Figure 7. An extended version of a subset of tracks shown in Figure 6.

The set of drifters deployed at eastern Kambal reef were purposely not recovered so the entire length of the northwest Mindoro strait would be sampled (Figure 7). Velocities remained at mostly more than 0.50 m s^{-1} during the entire 4 day (and counting) sampling period, with drifters moving through nearly the center of the channel. Even after 4 days, the integrity of the initial deployment grid remained mostly in tack. On the last sampling day of the cruise, SVP drifters were deployed in the region of the Microstars so that the fate of Mindoro strait water can be tracked even after the Microstars reach the end of their ~8 day sampling life. Finally, it is worth noting that while the first few drifter deployments were characterized by calm winds and seas, winds along the northwestern Mindoro were as large as 20 knots and mostly from the south-east with little curl on the cross-strait scale.

Mindoro Strait – Apo Reef Microstar Deployment

A set of 4 Microstar drifters were deployed just downstream of the eastern edge of Apo reef in hopes of observing stirring caused by the seamount (Figure 8). Originally, a grid of 6 drifters in a 2 x 3 array with the usual 1 km spacing was planned for a location as close to the reef as the R/V Melville could safely travel (~2.5 km). This location turned out to coincide with the outer edge of the marine protected area where fishermen congregate. Fishing traffic was so dense that the R/V Melville was unable to navigate to two of the stations. Thus, only 4 drifters were deployed. Two of these failed due to instrument malfunction, 1 was picked up by a fisherman and later redeployed, and 1 was picked up by a fisherman and taken to shore.

The two drifters that successfully sampled clearly show recirculation in the lee of the reef (Figure 9). All drifters began moving south-eastward, opposite the larger scale channel flow, at near 0.50 m s^{-1}. Cyclonic circulation toward the north-east, north, and north-west then occurred. After moving roughly 8 nm further down channel, the remaining drifter again moved with rapid cyclonic motion, ending with southward flow at ~0.20 m s^{-1}. The drifter deployed on the west side of the reef rotated anti-cyclonically, ultimately moving south-east at ~0.10 m s^{-1} in the lee of the reef.

Observations show recirculation, and not the generation of eddies and their movement downstream. This may be an artifact of the extremely sparse sampling. Apo reef clearly has the potential to induce significant vorticity into the flow. This region should be targeted for a more in depth study. With all the fishing traffic an extensive drifter study might prove difficult. Much could likely be learned from data collected as part of a towed survey in the lee of Apo reef. Similarly, the absence of vorticity in the lee of Kambal reef may arise from an overly sparse or improperly configured sampling strategy and the influence of smaller seamounts on the channel flow needs further investigation.

3. Summary/Comments

The timing of this report, due at the end of the cruise, dictates a bias toward discussion of sampling logistics, instrument performance, and a descriptive summary of drifter movement. Many drifters are still sampling including 7 SVP drifters that will hopefully record the regional circulation over many months to come.

A total of 30 Microstar tracks with an average length of ~2 days were collected with 12 drifters during the cruise. Sampling by 7 SVP drifters is still ongoing. The deployments mark the first use of more than a handful of drifters that transmit real-time position data to a research vessel through Iridium. Although 5 Microstar drifters were lost due to failure, the reason for failure was presumably discovered, and the drifters will be modified to avoid locking up when they are unable to communicate with an Iridium satellite. Deployment and retrieval from the R/V Melville was greatly successful. It was

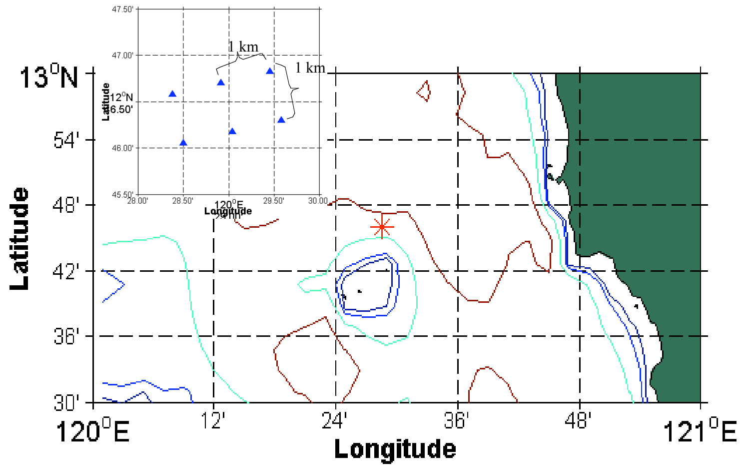

Figure 8. Deployment location near Apo reef. Inset shows drifter spacing at red star.

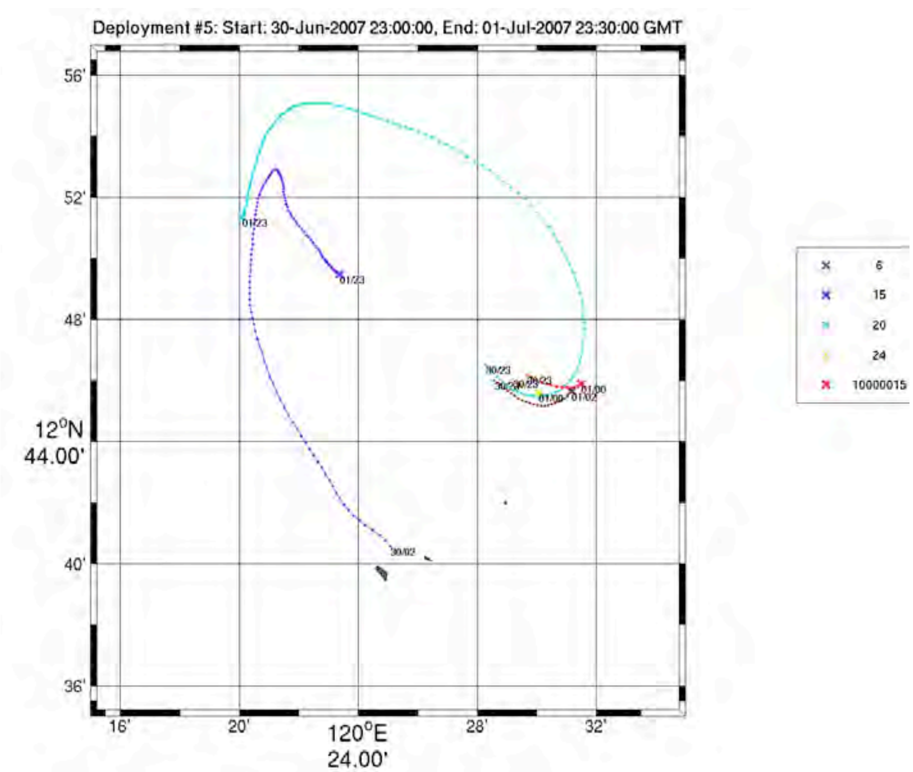

Figure 9. As in Figure 4 for drifters deployed near Apo reef.

occasionally difficult to find drifters in energetic flows when more than 20 minutes had elapsed since the last real-time position update. Drifter firmware is being modified so that each 10 minute position update will be received in real-time. A small increase in telemetry costs will result, but this should be more than compensated by decreased retrieval times. Three Microstar drifters were picked up by fishermen, an extremely small number given the density of fishing activity in the sampling area. Unwanted recovery can be partially remedied by maximizing nighttime sampling, and ultimately remedied by educating fishermen on the instruments and its benefit to them through science.

The drifters proved extremely complementary to the ships ADCP data for understanding the flow structure. The hull ADCP does not resolve the top ~20 meters of the water column. Off the west coast of Panay in the south sill region, the surface currents proved much different than those at 20 m depth. Finer resolution than available with ADCP data shows that energy on scales of 1 km or less can vary greatly within the archipelago. Knowledge of these eddy diffusivity values can be important for accurate model simulations of the flow. Finally, the Lagrangian nature of drifters enables circulation features in the lee of seamounts to be properly resolved as both the movement around an eddy and the movement of an eddy itself can be resolved. The fate of waters that originate in the Dipolog and Mindoro straits will ultimately be realized with continued updates from the drifters still sampling.